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JUNE 1987

AIR FORCE GEOPHYSICS LABORATORY

REPORT ON RESEARCH

For the Period January 1985–December 1986

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This is the thirteenth Report on Research at the Air Force Geophysics Laboratory. It covers a two-year interval. Although written primarily for Air Force and DOD managers of research and development, it is intended to interest an even broader audience. For this audience, the report relates the Laboratory's programs to the larger scientific field of which they are a part. The work of each of the Laboratory's seven scientific divisions is discussed in a separate chapter, followed by a listing of its publications. The report also includes an introductory chapter on AFGL management and logistic activities related to the reporting period. Keywords: Air Force research, Geophysics; [illegible], Space systems environments, Atmospheric physics, Lidar; Infrared/ultraviolet radiation;

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    Trans-Ionospheric Signal Propagation
    Rocket Instrumentation
    Upper Atmosphere Physics
    Upper Atmosphere Chemistry

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AFGL-TR-87-0188
JUNE 1987

Report on Research at AFGL

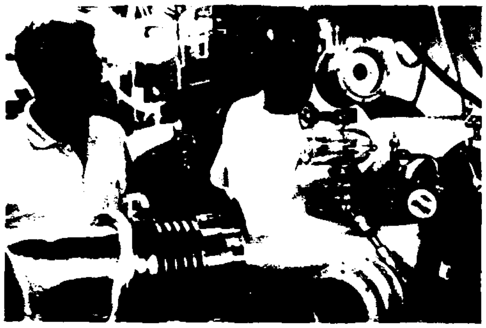
January 1985-December 1986

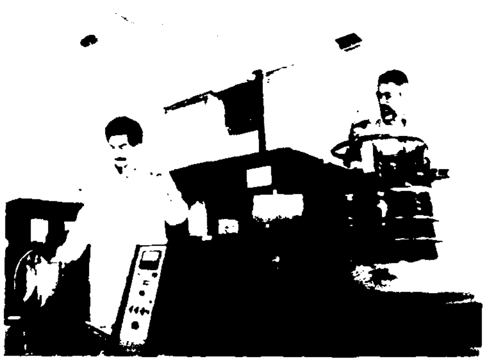
SURVEY OF PROGRAMS AND PROGRESS

THE AIR FORCE GEOPHYSICS LABORATORY

AIR FORCE
SYSTEMS COMMAND
HANSCOM AIR FORCE BASE
MASSACHUSETTS

June 1987





Foreword

This report summarizes the recent achievements and progress of ongoing programs at the Air Force Geophysics Laboratory. It is the thirteenth in a series initiated by AFGL's predecessor, the Air Force Cambridge Research Laboratories (AFCRL). Written primarily for Air Force and DoD managers of research and development, it shows how AFGL met the needs of Air Force systems and extended the technology base in geophysics during the period from January, 1985, through December, 1986.

JOSEPH R. JOHNSON
Colonel, USAF
Commander

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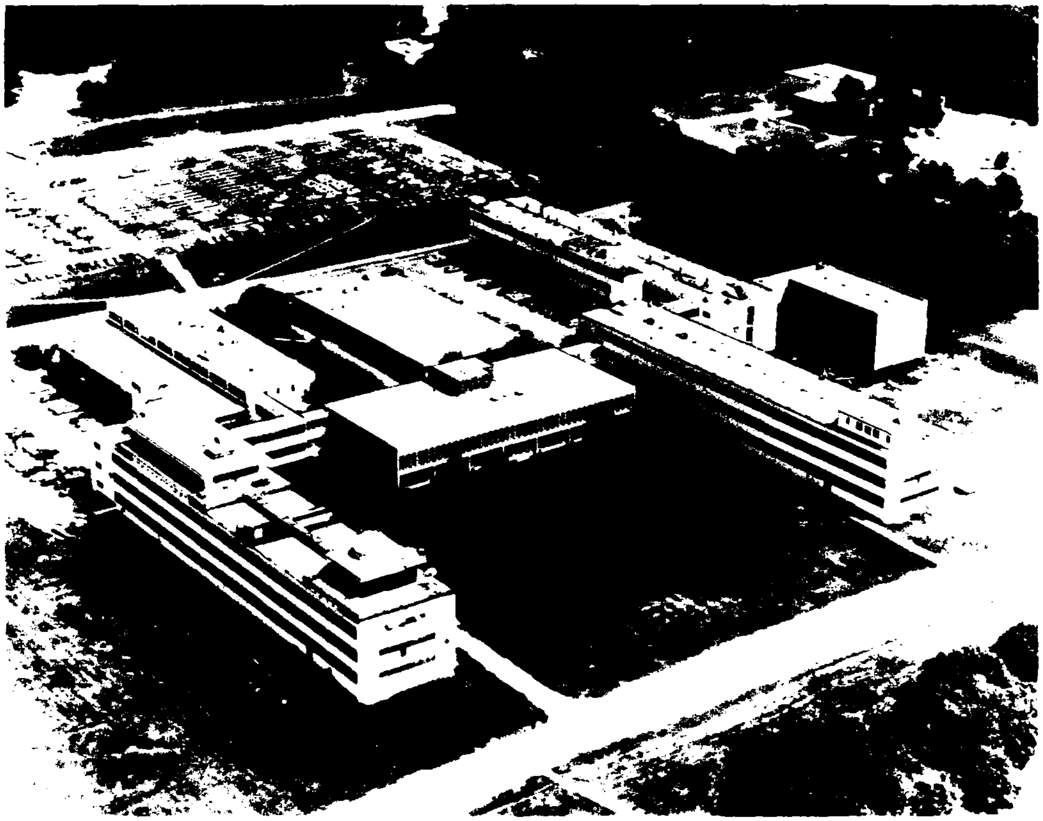


The Air Force Geophysics Laboratory is located at Hanscom AFB, 17 miles west of Boston. It is a tenant of the Electronic Systems Division of the Air Force Systems Command (USAF photo by Patrick J. Windward).

I AIR FORCE GEOPHYSICS LABORATORY

The mission of the Air Force Geophysics Laboratory (AFGL) is to understand the geophysical environment in which Air Force systems operate so that it can define design parameters for these systems.

AFGL is part of the Space Technology Center, headquartered at Kirtland AFB, New Mexico. The Center reports to the Space Division of the Air Force Systems Command, Los Angeles AFS, California.

This report describes the achievements and activities of AFGL from January 1, 1985, through December 31, 1986. During this period, AFGL conducted research, exploratory, and advanced development programs in the physics of space, the ionosphere, the atmosphere, the earth, and optics. The products of these research and development programs were transitioned into the Air Force as military design standards, computer-aided design tools, databases of geophysical effects, tactical decision aids, computer models of the environment and of its interaction with Air Force systems, feasibility studies, and prototype hardware and software.

In 1985, Colonel Joseph D. Morgan, III, commanded AFGL until July 18, when he was succeeded by Colonel Joseph R. Johnson, formerly Chief of the Strategic Command, Control, and Communications Division for the Deputy Chief of Staff, Research, Development and Acquisition. Colonel Rodney Bartholomew served as Vice Commander of the Laboratory until July 31, 1985, when he was replaced by Colonel James K. McDonough, previously Installation Commander at the New Boston AFS, New Hampshire. Dr. A. T. Stair, Jr., appointed Chief Scientist in January 1982, retired in December 1986.

HANDBOOK OF GEOPHYSICS AND THE SPACE ENVIRONMENT

In 1985 the Air Force Geophysics Laboratory published the fourth edition of its classic handbook for Air Force designers, engineers, and systems operators. Since 1965, when the third edition was published, the development of large rocket and satellite platforms for experimental payloads and the expansion of computer capabilities have greatly advanced knowledge of geophysics. The fourth edition emphasizes the space environment with chapters on the sun and its emissions, the earth's magnetic field, the radiation belts, the ionosphere, and the aurora. Air Force designers of space vehicles will find the section on electrical charging of spacecraft especially useful. Infrared astronomy, the properties of the near-earth atmosphere, and the earth sciences are also included. Selected bibliographies are given at the end of each chapter.

FORTIETH ANNIVERSARY

The Laboratory celebrated its fortieth anniversary year in 1986. Originally called

The AFGL Corporate Board: Seated (left to right): Dr. Robert A. McClatchey, Director of the Atmospheric Sciences Division; Col James K. McDonough, Vice Commander; Col J. R. Johnson, Commander; Mrs. Rita Sagalyn, Director of the Space Physics Division; and Dr. Donald H. Eckhardt, Director of the Earth Sciences Division. Standing (left to right): Lt Col Richard G. Galloway, Director of Geophysics Programs Division; Dr. Randall E. Murphy, Director of the Infrared Technology Division; Dr. Richard G. Hendl, Director of Technical Plans and Operations; Mr. Robert Skrivanek, Director of the Ionospheric Physics Division; Dr. Earl Good, Director of the Optical Physics Division; Lt Col John E. Holdner, Director of Research Services Division; Lt Col Jason Chapel, Director of Information Systems Management Division; Mr. Neal Stark, Director of the Aerospace Engineering Division; Ms. Eunice Cronin, Assistant for Management Information (USAF photo by Lee Stevens).

Adolph S. Jursa (left), Scientific Editor, and Marylou Tschirch, Assistant Editor, present the fourth edition of the *Air Force Handbook of Geophysics and the Space Environment* to Col J. R. Johnson, AFGL Commander (USAF photo by Lee Stevens).

Maj John A. Gaudet, Deputy Director of the Space Physics Division, demonstrates basic principles of physics at AFGL Open House. (The student seated on a revolving chair discovers how hard it is to turn a spinning wheel while she is rotating.) (USAF photo by Lee Stevens).

the Cambridge Field Station of the Army Air Forces, the Laboratory began recruiting scientists from the Radio Research Laboratory at Harvard and the Radiation Laboratory at MIT in August, 1945. It did not receive formal status, however, until June, 1946. The Cambridge Field Station became the Air Force Cambridge Research Laboratories (AFCRL) in July, 1949. After a major reorganization in 1976, AFCRL was redesignated the Air Force Geophysics Laboratory and electronic functions were transferred to the Rome Air Development Center.

Fortieth Anniversary events included an Open House in April, the dedication of a new Payload Verification and Integration Facility in July, and a gala Anniversary Dinner in October, at which Lt Gen James A. Abrahamson, Director of the Strategic Defense Initiative Organization, was guest speaker.

AFGL was named the Outstanding Aerospace Unit of the Year in Space Division by the Air Force Association of Los Angeles in 1986. Its unique contributions to the Space Division mission include building an infrared database for surveillance satellites, measuring the acoustic environment at the Space Shuttle launch complex at Vandenberg AFB, California, developing a ground-based laser radar to measure atmospheric density for shuttle orbits, and inventing a revolutionary technique to acquire missile plume signatures.

SCIENTIFIC STAFF

The talent and reputation of the scientific staff are the Laboratory's chief asset. Of the 254 scientists and engineers at AFGL, 95 have doctor's degrees, 76 have master's degrees.

Dr. George A. Vanasse, physicist in the Optical Physics Division, received the Harold Brown Award in 1985, the third Brown award to an AFGL scientist since 1976. Dr. Vanasse developed a revolution-

Lt Gen Forrest S. McCartney (center), Commander of Space Division until October 9, 1986, cuts the ribbon at dedication ceremonies for AFGL's new Payload Verification and Integration Facility. Assisting him are Maj Gen Thomas C. Brandt (left), Vice Commander of the Electronic Systems Division; Mark Allen, building contractor; and Col J. R. Johnson (right), AFGL Commander. (USAF photo by Lee Stevens)

ary instrument called BOSS (Background Optical Suppression System) to detect targets with low infrared signatures, such as missile plumes, against background interference. It enhances the effectiveness of infrared surveillance systems. The Air Force Weapons Laboratory and Space Division chose this instrument to obtain laser kill assessments for the Strategic Defense Initiative Programs.

Master Sergeant Roger W. Sands, research and development technician in the Earth Sciences Division, won the Defense Mapping Agency's Research Award in 1985 for his contributions to the design, construction, and operation of AFGL's transportable absolute gravimeter. He is the first enlisted man to win this award. The gravimeter is the only instrument available in the United States to measure absolute gravity for the Department of Defense. This knowledge is needed to achieve the accuracy required by our strategic weapons systems.

Mrs. Ruth K. Seidman, director of the AFGL Library, was named the Outstanding Technical Librarian in the Air Force in 1985, for her initiative in automating the library's catalog.

First Lieutenant Frank J. Iannarilli, research physicist in the Infrared Technology Division, was one of three Air Force officers awarded the Air Force Research and Development Award in 1985. He developed new data-analysis methods for infrared target signatures. He increased the efficiency of the data processing and analysis operation by a factor of ten. His methods were recently applied to the characterization of the infrared signatures of naval vessels in support of the Navy.

James H. Brown, Robert R. Beland, Edmund A. Murphy, 1Lt Susan Sheldon, and Edmond M. Dewan, of the Atmospheric Optics Branch, won an Air Force Systems Command Quarterly Science and Engineering Technical Achievement Award in 1986. They designed a unique optical turbulence sensor to be used in developing and siting ground-based lasers for the Strategic Defense Initiative Organization and the Department of Defense.

Ms. Margaret Ann Shea received the Commemorative Medal honoring 100 Years of International Geophysics from the Soviet Geophysical Committee of the USSR Academy of Sciences.

The prestige of the scientific staff is further evidenced by the election of AFGL scientists as fellows of their professional societies: the Optical Society of America (eight fellows), the American Association for the Advancement of Science, the American Meteorological Society, the Geological Society of America; and by senior membership in the Institute of Electrical and Electronic Engineers, and membership in the New York Academy of Science.

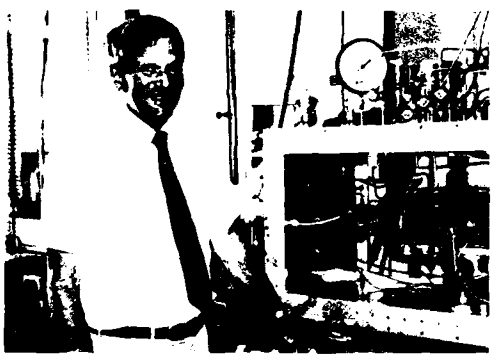
AFGL Fortieth Anniversary Dinner. (Head table guests include Hanscom AFB chaplain Father Manning (left), Mrs. Judith Johnson, guest speaker Lt Gen James A. Abrahamson, Director of the Strategic Defense Initiative Organization, and Col J. R. Johnson, AFGL Commander.) (USAF photo by Joseph Puglielli).

AFGL scientists also serve on committees of such international organizations as the International Scientific Radio Union (URSI), the International Association of Geomagnetism and Aeronomy (IAGA), the International Association for Meteorology and Atmospheric Physics (IAMAP), the International Union of Pure and Applied Physics (IUPAP), the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), and the International Union of Geodesy and Geophysics. (For a complete listing, see Appendix A.)

Laboratory scientists are also called to work on committees of many national organizations, both federal and professional, such as the National Academy of Sciences, the National Research Council, the Office of Science Technology Policy of the President, the American Geophysical Union, and the American Institute of Aeronautics and Astronautics. (A complete listing is given in Appendix B.)

A number of AFGL scientists are editors of professional journals and members of editorial boards, such as the journal of *Planetary and Space Science*; associate editor of the *Journal of Geophysical Research*; associate editor of the U.S. National Report to XIX General Assembly, International Union of Geodesy and Geophysics; co-editor, *Advances in Space Research*; co-editor, *Radio Science* (special issue on "Ionospheric Effects on Radio

Dr George A. Vanasse, physicist in the Optical Physics Division, received the Harold Brown Award in 1985 for developing a revolutionary technique to suppress background radiation from infrared signals and produce pure target spectra from low energy infrared targets, such as missile plumes (USAF photo by Lee Stevens).



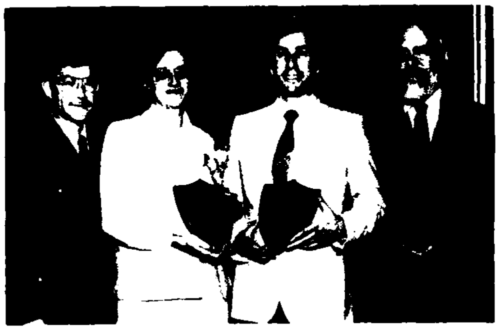
Dr. John F. Paulson, research chemist in the Ionospheric Physics Division, won the Laboratory's 1986 Guenter Loeser Award for his career achievements in atmospheric chemistry. (USAF photo by John F. Browne).

Systems," 1985); editor, "The Lower Atmosphere of Solar Flares," Proceedings of the National Solar Observatory/NASA Summer Symposium, 1985.

Many members of the scientific staff were invited to give lectures at important conferences, such as the High Resolution Solar Workshop, Munich, Germany, 1985; Fifth General Assembly of the International Association of Geomagnetism and Aeronomy, Prague, Czechoslovakia, 1985; Invited Professor, University of Paris, 1985; Fifth and Sixth Workshops on Maximum Entropy and Bayesian methods in Applied Statistics, 1985-86; COSPAR General Assembly ("White Light Movies of the Solar Photoflares from the SOUP Instrument Spacelab 2"; Chair, Plasma and Neutral Gas Injections, of Symposium on Active Experiments in Space), Toulouse, France, 1986; Fifth Symposium on Atomic and Surface Physics, Obertraun, Austria, 1986; Brotherton Lectures at University of Leeds, Leeds, United Kingdom, 1986; NATO Advanced Study Institute on Structure, Reactivity, and Thermochemistry of Ions, Les Arcs, France, 1986; American Chemical Society Meeting, 1986; Workshop on Trends and Perspectives in Fourier Transform Spectroscopy, Vienna, Austria, 1986; Workshop on Atmospheric Transparency, Capri, Italy, 1986; Bates International Colloquium on Atomic and Molecular Physics, Queen's University, Belfast, Northern Ireland, 1986.

To maintain its excellent technical staff, AFGL must interest the best young scientists in its mission and its technical programs. To accomplish this objective, the Laboratory has for a number of years participated in programs to attract and encourage young post doctoral scholars to continue their research at the Laboratory with internationally recognized experts in their fields.

One such program is the National Research Council Post Doctoral Associateship. Through this program, candidates receive one-year appointments (with an opportunity to renew for one additional year) as regular or senior appointees. Recently, there have been four or five such appointees at AFGL each year, including both United States and foreign citizens.



Dr. M. Susan Gussenhoven (left) and Dr. David A. Hardy (center), physicists in the Space Physics Division, and Mr. Ernest Holeman, AFGL contractor, shown here with AFGL Vice Commander Col. James K. McDonough, won the Laboratory's Marcus D. O'Day Award for their statistical study of auroral electron precipitation, in which they analyzed over 14 million electron spectra. (USAF photo by Joseph Puglielli).

The AFGL Geophysics Scholars Program was initiated in the fall of 1982. This program also awards one-year fellowships which can be renewed for an additional year. It is open only to citizens of the United States and is designed primarily to attract young scientists with newly awarded doctoral degrees and little or no nonuniversity experience. Geophysics Scholars have numbered eleven to thirteen over the past two years and have come from universities across the country. The contributions of these young men and women scientists, along with the ideas and enthusiasm they bring with them, are readily apparent and stand out as examples of the program's success.

Other programs in which the Laboratory participates are the USAF Summer Faculty Program and the Graduate Student Summer Support Program administered by the Air Force Office of Scientific Research. Qualified faculty members from universities across the country work at Air Force laboratories during the summer months. AFGL has benefited from twelve to fourteen such appointees each summer during the past two years. Two of the 1986 Nobel laureates in chemistry were formerly sponsored by AFGL: Professor John Polanyi and Professor Dudley Hershbach. Six graduate students were also working on research topics of interest to the Air Force during the summer of 1986.

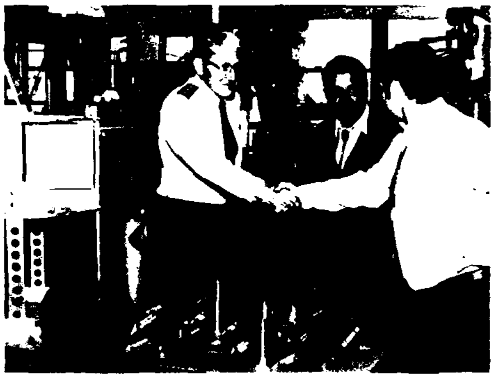
In response to Air Force concerns about a projected shortfall in scientists and engineers because high school students no longer seemed to be preparing for technical careers, the Laboratory initiated a high school apprenticeship program in 1985. Seven students from area high schools served eight-week apprenticeships under Laboratory mentors in each of the last two years. After learning FORTRAN and how to program the VAX 780, the apprentices contributed to such Laboratory programs as short-term high accuracy weather forecasts, an interactive weather display system, and the analysis of data for the Defense Meteorological Satellite Program.

The Laboratory sponsored twenty-one workshops in the reporting period in which scientists from the other services, government agencies, universities, and private contractors joined the AFGL staff to exchange information and plan research on topics of mutual interest. These include the Infrared Information Symposium, the Interactions Measurement Payload for Shuttle (IMPS) Experimenters Working Group, the AFGL/DARPA Nuclear Test Ban Monitoring Research Group, the USAF Mesoscale Technical Exchange Group, the Smoke and Aerosol Working Group of the Joint Technical Coordinating Group for Munition Effectiveness, and the Neutral Particle Beam Theory Meeting. As the technical agent of the Department of Defense for atmospheric transmission codes, the Laboratory conducts annual Tri-Service Review conferences on atmospheric transmission models and gives an annual workshop on the codes at Wright-Patterson Air Force Base. The Laboratory also conducts an annual Tri-Service Cloud Modeling Workshop to evaluate the effects of clouds on weapon systems and to incorporate cloud effects into war games. In 1985, the Atmospheric Sciences Division gave a tutorial on cloud simulation and cloud-free line-of-sight modeling for the Strategic Defense Initiative Organization. The Earth Sciences Division sponsors an annual Gravity Gradiometer Conference at the Air Force Academy with representatives from the Department of Defense, NASA, industry, and universities.

ANNUAL BUDGETS

The annual budgets for the two years covered in this report are shown in the accompanying table. The totals include salaries, equipment, travel, supplies, computer rental, and those funds going into contract research. The largest expenditure is for contract research and development.

Funds received from AFGL's higher headquarters, the HQ AFSC Director of Science and Technology (DL), and to a lesser extent those received from AFSC organizations other than headquarters, are used to conduct continuing programs.



Lt Gen Aloysius G. Casey, Space Division Commander as of October 9, 1986, tours the AFGL *machine shop, which supports the* Laboratory's scientific programs. Mr. George Trainer, Chief of the Fabrication Section, greets him, as Mr. Cornelius Regan, Chief of Operational Services, looks on.

AFGL receives support from the Electronic Systems Division, the host organization at Hanscom AFB, in accounting, personnel, procurement, security, civil engineering, and supply. Holloman AFB, New Mexico, provides services to the AFGL Balloon Detachment. AFGL supports two divisions of the Rome Air Development Center at Hanscom AFB in the areas of the Research Library, laboratory materials needed for the electronic technology mission, the computer, technical photography, mechanical and electrical engineering, laboratory layouts, electronic instrumentation, and woodworking.

AFGL contracts are monitored by scientists who are themselves active, participating researchers, and who plan the research, organize the program, interpret the results, and share the workload of the actual research.

TABLE 1
SOURCES OF AFGL FUNDS
FISCAL YEARS 1985 - 86

	FY 85 ($M)	FY 86 ($M)
Air Force Systems Command-DL	60.2	60.9
Air Force Systems Command-Other than DL	5.5	8.5
Defense Nuclear Agency	1.4	0.3
Defense Mapping Agency	4.8	4.6
Defense Advanced Research Projects Agency	2.8	3.5
Other Defense Agencies	19.0	16.4
Other Govt Agencies	0.5	0.2
	94.2	94.4

FIELD SITES

AFGL operates several field sites, the largest of which is the Ground-Based Remote Sensing Facility in Sudbury, Massachusetts. Here four meteorological radars and data acquisition and processing equipment, including Perkin-Elmer 3242 and Digital VAX 11/750 computers, support a variety of meteorological investigations.

In New Mexico, AFGL operates a balloon launch site at Holloman AFB and maintains the Solar Research Branch (seven scientists) of the Space Physics Division at the Sacramento Peak Solar Observatory, Sunspot.

At Goose Bay Station, Labrador, AFGL's Goose Bay Ionospheric Laboratory studies subarctic events, including the aurora and polar cap absorption of high-frequency radio waves.

AFGL carries out field tests at a number of military installations, including Sondrestrom AFB, Greenland, and the White Sands Missile Range, New Mexico. In addition, the Poker Flat Research Range, Alaska, and commercial airports are also used.

AFGL launched 34 research balloons during 1985-86 from its permanent balloon launch facility at Holloman AFB, New Mexico, and from temporary sites at Roswell, New Mexico, Ramona, California, and the Utah Test Range. Thirteen of these flights were tethered balloon missions.

During a series of landmark tethered operations, an AFGL 100,000 cubic foot aerostat was flown at a record-breaking altitude of 22,500 feet above sea level. It carried a target for a small, radar-guided missile. Flying on a 4-mile long tether anchored to a tank, the aerostat was safely towed over the desert to change the position of the target.

Free balloons launched from remote sites to fly in the stratosphere over specified, limited test areas were also successfully flown for the SCRIBE 99 and KESTREL programs. Both payloads had precise pointing platforms controlled by radio command.

AFGL conducted test and experimental balloon missions for Space Division, the Electronic Systems Division, the U.S. Army, U.S. Navy, U.S. Marine Corps, the

Defense Mapping Agency, the Defense Communications Agency, NASA, and several universities.

In 1985-1986, five sounding rockets were launched in support of AFGL scientists. Four flights were totally successful, but a vehicle system failed on one. All payload systems performed as planned.

Development of four sounding rocket payloads began in 1986 for launch in 1987. About one half the technical effort normally applied to research vehicle work is now devoted to free-flying satellite and shuttle payload-system integration. In the reporting period, experiments were flown on one free-flying satellite.

Technology-based research has continued in the areas of microprocessor-based adaptive telemetry systems, intelligent data-processor systems, and command/control systems. An adaptive controller was developed for use on Get Away Special shuttle payloads.

LIDAR SOUNDING LABORATORY

AFGL's laser sounding laboratory GLEAM (Ground-based Lidar Experiment for Atmospheric Measurements) has been used to develop techniques for sounding atmospheric properties. During the past two years, density and temperature measurements have been made using molecular scattering. The technique holds the promise of providing remote measurements of atmospheric density and temperature profiles which could eventually replace most of the current effort with meteorological rockets. A tunable laser has been added to study the sodium layer deposited by meteoric dust between 80 and 100 km.

During the period, a mobile lidar sounder has been developed and tested. The instrument was assembled during the summer of 1985 and tested at AFGL. The trailer was taken to Wallops Island, Virginia, in September, 1985, and the sounder was used in a meteorological study. The instrument was transported to Alaska in January, 1986, and obtained a database on high-latitude atmospheric density variability to assist in decisions on shuttle reentry from polar orbit.

AFGL Mobile Lidar Unit at Poker Flat, Alaska.

AFGL COMPUTER FACILITIES

AFGL is continuing to update its computing facilities. The former Computer Center, which consisted of a large, central-site processing facility, has been augmented with a broadband Local Area Network interconnecting the mainframe computer and numerous medium-size virtual memory hosts. The hosts are a CDC Cyber 180-860, a VAX 8650, and a VAX-11/780. A pilot network which has been operational since the spring of 1983 consists of three main host systems and numerous intelligent terminals, such as IBM personal computers, Tektronix color graphic terminals, as well as a number of DEC VT100 and VT200 type terminals. The fully operational network was implemented in December, 1986, and is valued at $19 million.

A long range evolutionary plan completed during FY84 is being carried out to provide a migration toward an advanced, full capability distributed, multimedia information system. This plan addresses future network enhancements and services, translation of future user needs into information system capabilities, the time-phasing of information systems growth, and the identification and definition of viable alternative information system architectures to meet the stipulated evolutionary needs. A new plan is being developed to further respond to the needs of the AFGL user community for the next five years.

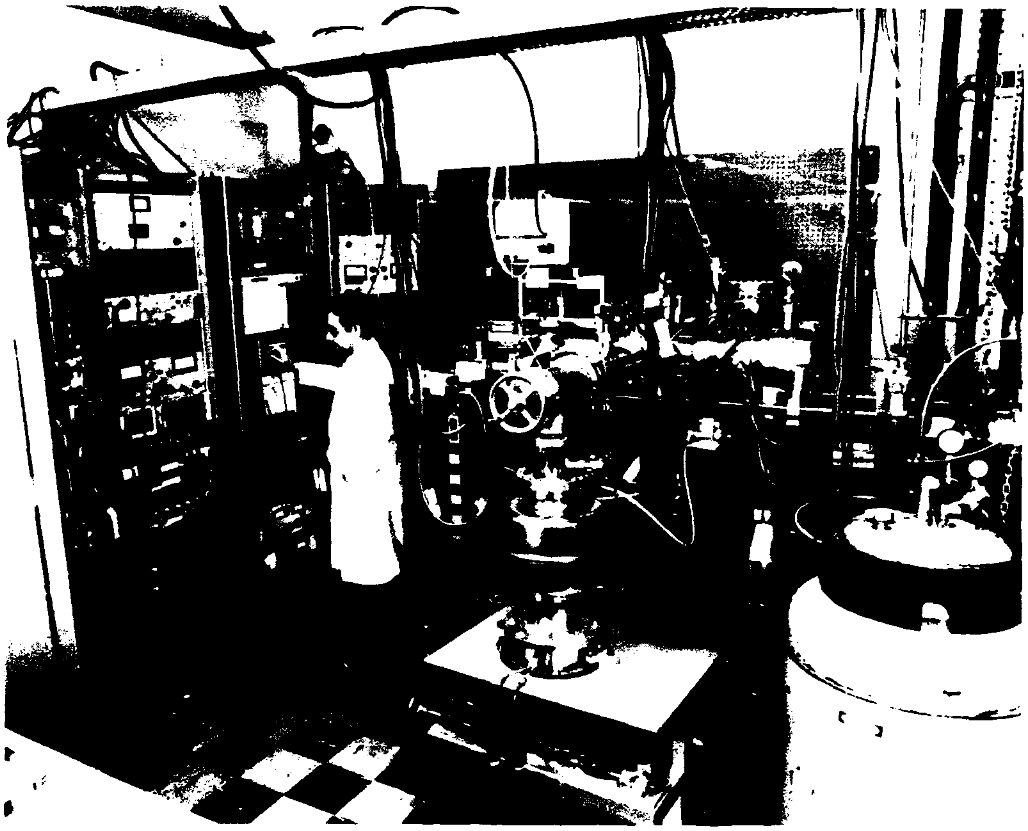
AFGL RESEARCH LIBRARY

The AFGL Research Library has the largest and most comprehensive scientific and technical research collection in the United States Air Force. This collection is international in scope and includes extensive holdings in mathematics, chemistry,

The diverse collections of the AFGL Library permit it to mount a variety of exhibits throughout the year. Here Eleanor Gildersleeve, Serials Cataloguer, and Ellen Dobi, Chief of Reference and Circulation Services, view the Matthew Henson exhibit, which presented the true story of the discovery of the North Pole.

physics, astrophysics, electronics, and geophysics. Each year the library adds more than 2,500 new titles to the book collection. The library also subscribes to approximately 1,800 current periodical titles. Of these, approximately 4,000 volumes are bound each year and added to the permanent collection. Inhouse and contractor technical reports from AFGL and the Electronic Systems Division are also maintained, both in paper and microfiche.

In addition to its collection of publications, the library offers computer-aided literature searches of the Defense Technical Information Center's (DTIC) extensive files, as well as many commercially available databases. This service provides the patron with immediate access to millions of citations from journals, books, reports, proceedings, and reviews published throughout the world.



Double Mass Spectrometer Used to Measure Cross Sections of Ion Neutral Reactions.

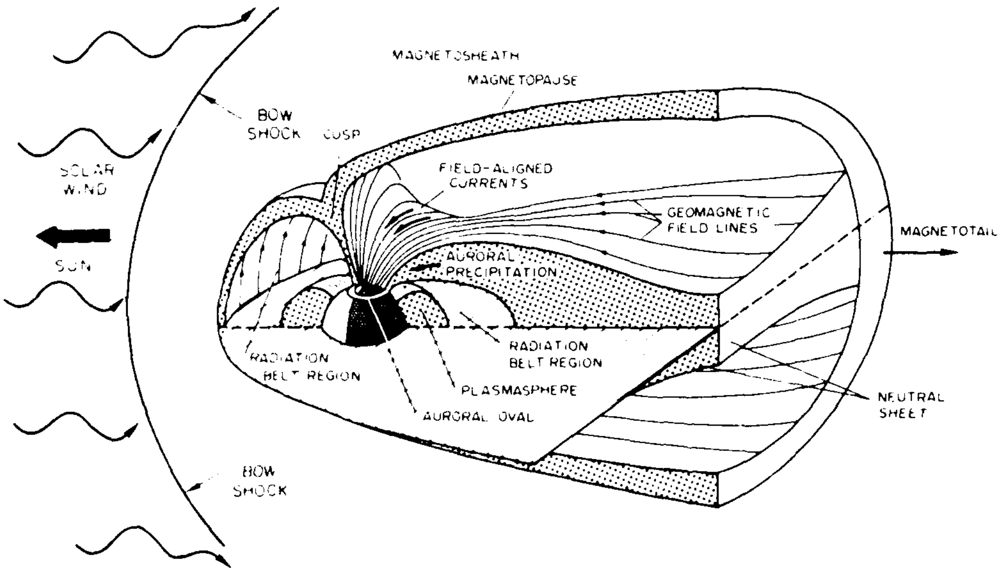
II SPACE PHYSICS DIVISION

The Space Physics Division conducts the basic research and advanced development in the solar-terrestrial system required for the development of the next generation of Air Force space systems. The results are essential to the design of survivable, reliable space systems and to the conduct of increasingly complex Air Force space operations. The results are applied directly to the development of space weather forecasting tools, to space systems design, and to optimizing the performance of command, control, communication, and intelligence systems.

The sun is the primary source of energy in the solar-terrestrial system. Understanding the physical mechanisms responsible for solar emissions is essential to the success of the Air Force space mission. The Solar Research Branch of the Space Physics Division studies fundamental solar processes, including the emission of electromagnetic radiation, energetic protons, cosmic rays, and the solar wind. Solar-particle, plasma, and electromagnetic emissions determine the characteristics of the interplanetary medium: the solar wind and the interplanetary magnetic field. The solar wind, in turn, is a major determinant of the shape and size of the magnetosphere-ionosphere cavity (see the figure), and of the energetic particle content of the magnetosphere. The solar flare is the most striking example of solar disturbances which can produce catastrophic effects on Air Force space systems. Exciting results have been achieved from the solar experiments on Spacelab 2, including a new understanding of granulation in solar magnetic-field regions and the nature of large-scale solar motions.

Most Air Force space operations are carried out within the ionosphere-magnetosphere system, as shown in the figure. The outer boundary, the bow shock, is located approximately 10 earth radii upstream from the earth along the sun-earth line. The inner boundary is identified as the base of the ionospheric E-layer at approximately 100 km. Within this system, regions of great importance to Air Force operations are the earth's radiation belts and the high-latitude regions, including the auroral zone and polar cap. The performance of Air Force space systems is profoundly affected by energetic particles found in the Earth's magnetosphere. For example, these particles can seriously degrade electronic components or cause single event upsets (SEU's). On both the surface and interior of spacecraft they can also cause charging and discharging of materials which couple to spacecraft electronics. Unusually high particle fluxes generate a radiation hazard for manned spaceflight and can interfere with high-frequency radio communications in the Earth's polar regions.

To address these problems, the Space Physics Division is studying the processes governing the energetic particle environment, beginning with the origin of the particles in the solar atmosphere, their travel through the interplanetary medium, their acceleration in the Earth's magneto-



Model of the Magnetosphere Showing Major Particle Populations sphere, and their effects on space systems and the ionosphere. Much of the recent work has focused on forming an integrated picture of this process, combining the results of solar-flare research with solar wind and magnetospheric models to provide a more complete specification and new analytical representation of the dynamical nature of energetic particle populations in the space environment. The goal of the Space Physics Division is to develop a capability to model, monitor, and predict the behavior of the entire solar-terrestrial system.

To carry out these programs, state-of-the-art space flight and groundbased diagnostics must be developed, and analytical and phenomenological models of the system derived. During the past year, 18 spaceflight instruments were delivered to the SPACERAD/CRRES (Space Radiation/Combined Release and Radiation Effects Satellite) integrator. A principal goal of this program is to accelerate the transfer of new microelectronic technologies to Air Force space programs. The SPACERAD satellite will continuously traverse the earth's radiation belts. The payload includes a wide range of advanced microelectronic devices and wave, particle, and field sensors. This program will establish the in-flight performance of microelectronic devices, will relate causes of device degradation or failure to environmental conditions, and will generate the first dynamic models of the earth's radiation belts.

The high latitude ionosphere-magnetosphere-thermosphere region is being intensively studied by means of satellites, aircraft, rockets, and ground-based instruments. The results from Space Physics Division particles, fields, and plasma instruments on the DMSP spacecraft have provided an important new data source for space weather prediction. Further, the analysis of the flight results have led to significant discoveries about energy and particle transport across the boundaries of the solar-terrestrial regions. Factors contributing to large-scale thermal plasma motions and the production of small-scale irregularities which produce scintillations in radio and radar signals have been determined. The results contribute to the operation of Air Force communication and surveillance systems operating at high latitudes. Magnetic substorms are initiated when the energetic particles in the earth's plasma sheet and dayside cusp are suddenly accelerated along open magnetic field lines into the near-earth environment. Studies of ionosphere-magnetosphere coupling will lead to a capability for predicting substorms and auroral and polar cap ionization. The results will contribute to models of satellite drag, auroral infrared emissions, improved frequency management, and to specification of conditions under which serious signal loss and unacceptable fade margins will develop in high-latitude communications systems.

More complex, larger, high-powered spacecraft are planned for future Air Force missions. The development of our understanding of the interactions between space systems and the environment is crucial to the proper design of these systems. Ongoing Space Physics Division basic, applied, and exploratory research and development efforts focus on several space systems/environmental interaction problems including spacecraft charging, techniques of charge mitigation, spacecraft contamination, spacecraft signatures, degradation of surface materials, and on the development of design guidelines for future space systems. Measurements of spacecraft particulates on

Shuttle Mission 61-C in 1986 have provided an important database for testing shuttle contamination codes and for assessing the effects of particulates on space sensor performance. Space-system environmental-interaction charging codes and large space-structure models have been developed.

The Active Space Experiment program investigates the effects on the environment of the emissions of chemicals, waves, beams, and high-power rf signals. Theoretical developments during the past decade and advances in diagnostic sensors used to monitor the environmental effects produced by active emissions make active experiments highly feasible. A beam emission rocket test (BERT) was successfully conducted for the study of charged particle-beam transport and for determination of the effects of beam emission on the host vehicle. Hitherto unobserved beam-induced waves were measured, which provided a new understanding of beam propagation effects.

The Division program is carried out by means of in-house laboratory efforts, an extensive field program, and a broad contractual program. The field programs involve satellite experimentation and rocket, aircraft and ground-based investigations. The ground-based program includes solar studies at the Sacramento Peak Observatory in New Mexico. Highlights of the discoveries and advances in solar-terrestrial physics by Space Physics Division scientists during the past two years are described in the following sections.

SOLAR RESEARCH

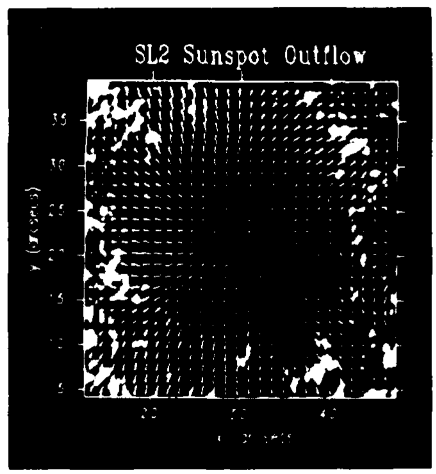
Solar research is performed within the Space Physics Division by the Solar Research Branch, which has sole responsibility within the Air Force for developing new techniques to predict the occurrence of activity on the sun. Its primary task is to identify, predict, and understand those physical mechanisms on the sun that cause solar flares, high-speed solar wind streams, and coronal mass ejections, because these in turn produce geophysical disturbances that disrupt Department of Defense satellite systems and aircraft operating in the space environment.

The Solar Research Branch also has programs to improve our understanding of basic solar phenomena through space-based observations, image enhancement, and observations of solar-like stars. Branch personnel participated in NASA's Spacelab 2 mission and are co-investigators on NASA's Sunlab (the reflight of the solar instruments from Spacelab 2) and High Resolution Solar Observatory (HRSO) missions. In addition, several experiments have been proposed for the Space Test Program of the Air Force Space Division. These missions will provide solar data in the x-ray and extreme ultraviolet spectral regions which are unavailable from the ground but are of fundamental importance to understanding solar activity.

Spacelab 2 Results: One of the most exciting projects carried out by the Solar Research Branch during 1985-1986 was helping to plan, execute, and analyze data from the Spacelab 2 mission (NASA's Space Shuttle Flight 51-F, July 29 - August 6, 1985). Spacelab 2 carried four solar telescopes among its payload of fourteen experiments. One of these was the Solar Optical Universal Polarimeter (SOUP) built by the Lockheed Palo Alto Research Laboratory. Solar Research Branch scientists have been involved with this project as co-investigators (one also as a payload specialist astronaut) since its inception a decade earlier in 1977. SOUP contains a 30-cm Cassegrain telescope, an active secondary mirror for image stabilization, and a white-light optical system with 35-mm film and video cameras. SOUP was designed to study granulation, sunspots, magnetic fields, and velocity fields in the photosphere. These data are diffraction-limited at 0.5 arcsecond resolution and are free of distortions. For most of the data the interval between exposures was 2 seconds. Data analysis is still in progress, but preliminary results have shown many interesting and unexpected features:

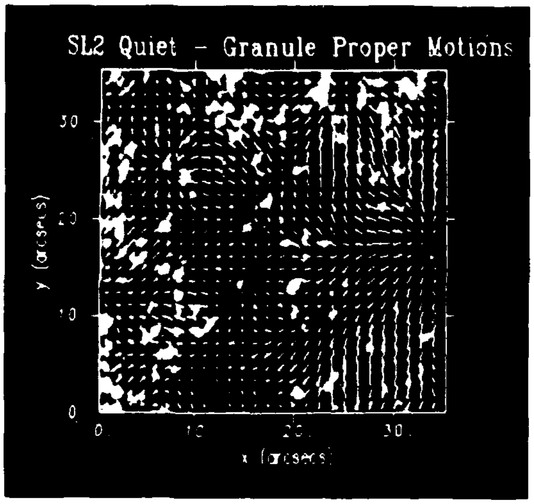
1. Granulation - It was determined that granules (tiny bubble-like convection cells) in magnetic regions (sunspots, pores, and network boundaries) are very different from granules in the quiet, undisturbed sun. They differ in size, rate of intensity variation, and evolution. Movies show that the shapes of very small magnetic pores embedded in the granulation are irregular, scalloped, and rapidly changing as they attempt to maintain their structure against the encroachment of turbulent surrounding granules. Spacelab 2 movies, which provide the first undistorted histories of granule evolution, have led to the discovery that *more than half of all granules die a violent death* -- they don't just quietly fade away. Either they expand until they reach a critical size and explode into many tiny fragments, or they are destroyed by a nearby explosion. The movie also shows that granular lifetimes, which can be used to measure the effective diffusion constant associated with convection, are much longer in regions with strong magnetic fields.

2. Large-scale Flows - Normally, motions on the sun are measured by the Doppler effect. Since the Doppler effect measures only line-of-sight velocities, however, it cannot be used to determine horizontal motions at disk center. The only way to observe such flows is through proper motion studies using solar features as tracers. Granules are the obvious choice as tracers of photospheric flows, but because of their small size, coupled with the blurring and geometric distortion due to atmospheric turbulence, they have proved to be extremely difficult to use in earlier ground-based observations. During its 10 minute lifetime, a typical granule might move only a few hundred kilometers, about 0.3 arcsecond, which is much less than the size of the random fluctuations caused by atmospheric seeing, even under the best conditions. Now, however, with the high-quality distortion-free movie sequences from SOUP, it is possible to measure granulation proper motions with high accuracy.



Map Showing the Average Displacement of the Local Granulation Pattern Superimposed on Image of Sunspot Region.

Radial outflow of the granulation from a sunspot has been a striking new discovery. Movies temporally filtered to suppress the 5 minute oscillations show the

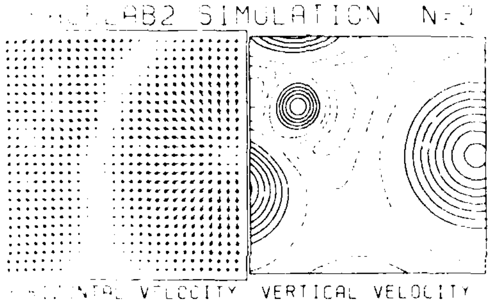


Average Flow Field in Quiet Solar Region (No Magnetic Field) Superimposed over Image of Quiet Sun

motion most clearly and allow an estimate of the velocities of individual granules, which typically range from 0.3 to 1.0 km per second. The outward motion may be upward convection deflected by the magnetic field of the sunspot. These measurements should be an important contribution to theoretical models of the sunspot penumbra and its effect on photospheric convection. Besides the constant advection of granules away from the spot boundary, there are also a number of bright ejections from the penumbra which travel at 2-3 km per second. These high-speed events seem to be associated with elongations of the penumbral filaments. Local correlation tracking techniques have been used to obtain quantitative information about the flow field. At each pixel in the image, the displacement between successive frames is measured by cross-correlation between successive frames of the movie within a 3-5 arcsecond window centered on the pixel. The vector displacements from many comparisons are used to produce an average displacement map; an example is shown overlaid on the sunspot image in the figure.

The correlation tracking technique also reveals larger scale flow fields. In addition to the diverging flow from the sunspot in the figure, there are many areas in the quiet granulation pattern which are loci of inflow (sinks or sources). Most of the 40 x 40 arcsecond region of quiet sun used for the study of exploding granules is shown in the next figure, overlaid by the average flow field. Typical velocities are in the range of 0.3-0.7 km per second. The large-scale flow fields, both as observed visually from the movies, and quantitatively from the calculated vector displacements, have the proper size and appearance of super and mesogranular convection flows. Mesogranules, intermediate in size between granules and supergranules, have been clearly observed for the first time in these Spacelab 2 movies. These flows can be expected, at subsurface levels in the sun, to move magnetic fields to the cell boundaries, and form the loci of the photospheric and chromospheric networks. Excellent ground-based magnetograms and chromospheric spectroheliograms from the Big Bear Solar Observatory taken simultaneously with the SOUP data have been compared with the SOUP flow fields. They are in perfect agreement and confirm at last, some 25 years after the discovery of supergranulation, the intimate relation between convection and magnetic forces in the sun.

3. Flow Modeling - Efforts are in progress to simulate the flow patterns using analytic axisymmetric functions which satisfy the mass continuity equation of a convection plume in the solar surface. A number of such sources can be used to create a regular cellular pattern of con-

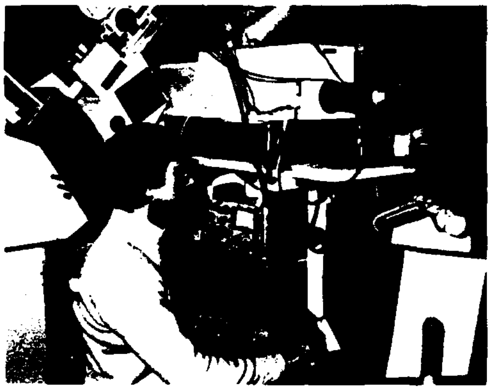


Superposition of Four Theoretical Plume Functions Used to Model the Flows Observed in the Quiet Sun (Left: Horizontal Velocities Associated with the Plumes; Right: Upflows, Solid Contours, and Down Flows (Dotted Contours). Note the similarities between the observed horizontal flows in the preceding figure and the computed flows shown here).

vection. By using the coordinates of the distinct squares in the preceding figure as the loci of four plumes, the resulting flow pattern can be calculated according to the model, and it is possible to mimic the observed motions remarkably well using a superposition of plume functions, as seen in the next figure.

4. Conclusion - These striking new results have been obtained from only a preliminary analysis of a small part of the SOUP data. Already, a number of new phenomena have been seen which are forcing revisions to the conventional ideas of the nature of solar granulation and its evolution. It is quite clear that, although spatial resolution was limited by the SOUP telescope's small 30-cm aperture, the absence of the turbulence found in the earth's atmosphere, which always degrades ground-based observations, resulted in by far the most outstanding time series of solar granulation ever obtained and has opened a new window through which to view the sun's surface.

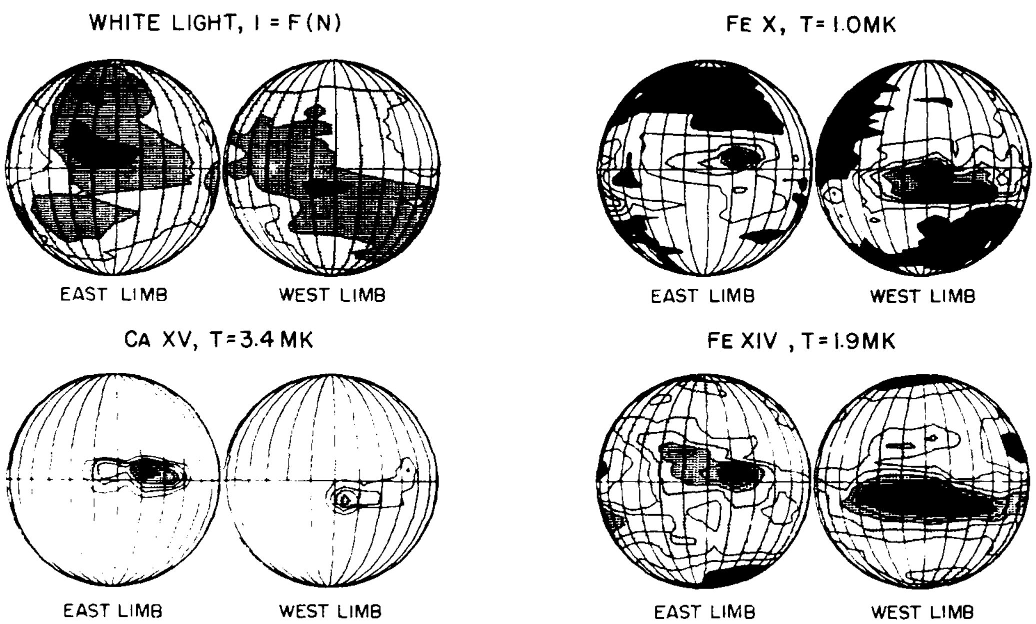
Studies of Solar Coronal Data: The objective of this Air Force program is to improve our capability to understand and predict solar-caused geophysical disturbances that degrade or even disable some Air Force systems. Particles and electromagnetic emission from the sun have been shown to cause geophysical disturbances (GD) in the magnetosphere, auroral zones, upper atmosphere and ionosphere which degrade Air Force systems that rely on the transmission or reception of electromagnetic radiation, such as communication, command, control, and intelligence systems. The solar source of GD often either lies in the solar corona and/or causes visible changes in the corona that can be used to predict the occurrence of GD.



Dr. Richard Altrock works at the computer console that controls the Emission-Line Coronal Photometer (ELCP). (This instrument obtains the daily observations of the solar corona used to analyze solar-activity production and to provide data to USAF space-environment forecasting centers. The ELCP filters and photomultiplier are in the white box to the upper right of Dr. Altrock's head. Light enters the box from the array of distribution tubes above the box, which in turn comes from the 16 inch diameter Coronagraph at Sacramento Peak.)

A joint observational program to investigate coronal features was established between AFGL scientists and scientists at the High Altitude Observatory (HAO) in Hawaii. White-light (visible continuum) coronal measurements from HAO were combined with AFGL measurements of the emission-line corona (spectral lines emitted from high ionization stages of coronal atoms) made with the Emission-Line Coronal Photometer (ELCP) shown in the figure. This allowed study of the temperature and density structure of the corona. White-light intensity is proportional to the total density of the corona along the line of sight, while the three emission lines (Fe X, Fe XIV, and Ca XV) show the density in cool, average, and hot parts of the corona, respectively. This data-base, covering an entire 11-year solar activity cycle, is unique in the history of ground-based solar observations. Photoelectric observations of this quality, length, and comprehensiveness have never before been available.

The observing systems record the intensity of the corona above the limb (edge) of the sun by scanning detectors in a circular path at a given distance from the limb. The figure shows how scans covering a 15-day period are joined together to produce a continuous chart, which is in turn projected onto the surface of a sphere to



Coronal Maps (Pictures of Coronal "Surface") in White Light and in Light from Fe X 6374Å, Ca XV 5694Å, and Fe XIV 5303Å. (The white-light maps depict the distribution of electron density. The emission-line intensities are proportional to the square of the electron density in regions having the indicated temperatures in millions of degrees Kelvin. In addition, East-limb data, which are rotating onto the visible solar disk, and West-limb data, which are rotating out of sight onto the back of the sun, are treated independently. The data show a snapshot of the front (left: East-limb data) and back (right: West-limb data) of the sun on May 14, 1984.)

produce a synthetic image of the solar disk. A separate image is made for each of the four observing modes described above.

Results from this program are as follows: (1) The bases of coronal streamers (elongated high-density structures that reach out to the orbit of the earth and which may cause significant changes in satellite drag) are easily seen near the central meridian (the darkest non-black shading) in all four modes of observation. (2) The emission-line images show that temperatures from 1.0 to 3.4 million degrees Kelvin are co-spatial (to within the 1 arc-minute resolution of the system) at the base of the streamers. This has important ramifications for models of energy transport within coronal active regions. (3) Regions of low density in the corona, known as "coronal holes" because of their appearance on x-ray images of the corona, can be easily identified in both white-light and Fe XIV observations. Since coronal holes are known to be the source of steady-state high-speed particle streams (HSS) in the solar wind, which cause some of the GD, these observations may be used to both study this interesting phenomenon and improve real-time predictions of the impact of HSS on the earth. (4) Solar regions that produce the most energetic flares (which cause the strongest GD) are covered by a canopy of high temperature coronal material that is easily visible in the Ca XV observations. This emission, never before seen with the high signal-to-noise ratio now available, provides space-forecasting centers with a powerful tool for detecting the presence of these regions before they rotate onto the solar disk and can release their devastating radiation towards the earth.

The Fe XIV green line data have proved useful for a number of other research and forecasting efforts:

1. Coronal Synoptic Charts for Solar Research-AFGL data obtained with the Emission Line Coronal Photometer have begun to appear in the form of Carrington synoptic charts (similar to a Mercator projection) in *Solar Geophysical Data,* a monthly publication of the National Oceanic and Atmospheric Administration (NOAA). Daily intensity plots from this instrument have been published there since 1978, and they will continue to appear in the daily-data section of the Prompt Reports. The synoptic charts display the absolute intensity of the corona in the green Fe XIV 5303 Å line at 0.15 solar radii (R_0) above the limb as a function of the day of central meridian passage. Charts for both west- and east-limb data are published in order to permit comparison of coronal evolution over two-week periods. The data are both contoured and shaded for either detailed study or quick determination of the location of active regions and coronal holes. Previous synoptic maps, extending back to 1973, are in press at the National Center for Atmospheric Research, and will soon be available from the Solar Research Branch.

2. Forecasting Solar Radio Flux - Cooperative research between the Solar Research Branch and the Air Force Global Weather Central Space Environmental Support Branch (WSE) has shown that the Fe XIV scans are useful for predicting the solar 10.7 cm radio flux. WSE is tasked with making such a prediction for 1, 2, and 3 days in advance. As a consequence, the Solar Research Branch now telecopies the daily scan to WSE within an hour of its production. These timely data are used by WSE forecasters to produce the forecast. In addition, forecasters use global solar

maps of coronal intensity that are telecopied from the Solar Research Branch to predict geomagnetic disturbances resulting from coronal holes and energetic solar active regions.

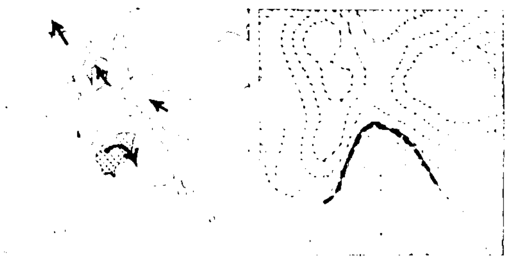
3. Relating Coronal Emission-Line Transients to Hydrogen Alpha Activity - In late 1982 a program was begun at the Solar Research Branch to patrol for slow coronal transients in Fe XIV. Over a period of 2.3 years, 296 hours of observations were successfully obtained on 49 days. During this period we recorded 14 emission-line transients that were associated with H-Alpha activity at the limb as seen in Sacramento Peak Observatory Flare Patrol films, for an average transient rate of 1.1 per 24 hours. No transients were recorded in the first third of 1985. The rates for 1983 and 1984 were equal, being 1.4 transients per 24 hours. These low-coronal transients were associated with surges or eruptive prominences at the limb 93 percent of the time. On only one occasion did we observe a transient associated solely with a flare. We conclude that low-coronal emission-line transients are highly associated with the ejection of chromospheric matter into the corona, in agreement with the earlier photographic study of DeMastus, Wagner and Robinson (Solar Phys. 31, 449, 1973). This conclusion is expected to help improve the capability of the Air Force to predict Coronal Mass Ejections, which are known to produce adverse effects on Air Force systems if they impact on the magnetosphere.

4. Overlapping Solar Cycles as Discovered in Coronal Fe XIV Emission - Investigation of the behavior of coronal intensity above the limb in an Fe XIV emission line obtained at the Solar Research Branch over the last fourteen years has resulted in the discovery of a second set of zones of solar activity at high latitudes that parallel the Main Activity Zones (MAZ), which progress from approximately 30° latitude to the equator over the solar cycle. Localized emission peaks in Fe XIV 5303 Å are observed through most of the cycle at high latitudes in individual daily scans, annual averages, and solar-cycle summary plots of the location of all local maximum intensities at 0.15 (R_0) above the limb. These peaks evolve slowly over a period of days, consistent with the rotation over the limb of stable features, similar to the lower-latitude peaks that are connected with active regions. The high-latitude coronal activity zones first appear at latitudes of 70° to 80°, 2-3 years after solar minimum. They evolve parallel to the MAZ, with the average latitude decreasing at a rate of roughly 3° per year. After their appearance, they are present more or less continuously until the following solar minimum. As we approach solar minimum, the high-latitude coronal activity zones that appeared after the beginning of Cycle 21 have monotonically evolved into the MAZ Cycle 22. It thus appears that we have evidence for parallel overlapping solar cycles that begin every 11 years but last for approximately 19-20 years. If sustained, this conclusion will have a revolutionary effect on our understanding of how solar activity is created.

Use of Interplanetary Radio Scintillation for Geomagnetic Forecasting: On April 9, 1986, AFGL contractor P.I. Bernard V. Jackson, University of California at San Diego, began sending forecasts of the solar wind speed at the earth to the USAF/NOAA Space environment Forecast Center in Boulder, Colorado. The forecasting algorithm was developed under a contract awarded by the Solar Research Branch. The observations used to produce the forecast, also supported by the Solar Research Branch, consist of radio-telescope recordings of the scintillation experienced by radio waves from extra-galactic sources as they pass through the turbulent solar wind. Theoretical and empirical studies of such scintillation have shown that the speed of the solar wind can be inferred from the observations. In this manner, a daily map of solar wind speeds at different distances from the sun, and at different position angles relative to the sun, can be produced. Analyses of these daily "snapshots" are used to detect the presence of high-speed streams in the solar wind and to predict their impact on the earth. They can lead to geomagnetic disturbances that produce adverse effects on Air Force systems. The forecast center notifies responsible parties of solar wind conditions for their use in operations planning. This additional capability will produce a significant improvement in the ability of forecasters to correctly forecast solar wind conditions.

Solar Flare Forecasting: The development of the techniques for predicting solar flares is a major goal of the flare research conducted by the Solar Research Branch. The problem is approached both through studies of flare physics and by means of statistical methods that provide objective forecasts using solar data that are currently available on a daily basis. One method, Multivariate Discriminant Analysis (MVDA), uses data collected by the Air Weather Service Solar Observing Optical Network (SOON). These data are converted to daily parameters describing active region morphology, dynamics, rate of growth, and magnetic structure; once in parameter form they are applicable to the MVDA program for deriving classification functions on which a forecast is based. Comparison with conventional, subjective techniques shows the objective, computer-generated forecasts to be superior in predicting flare activity on a 24-hour basis. Further improvements will depend on the availability of more consistent input data as well as the inclusion of new parameters based on the physical processes and energy storage mechanisms of the flare (see below). Short-term (0-30 minute) prediction techniques rely on early recognition of the irreversible changes which lead to the flare eruption. Before the impulsive release of x-ray and particle emission, the actual flare onset is often visible in certain optical absorption features, microwave polarization characteristics, and soft x-ray signatures. Studies indicate that the early detection of virtually all major flares would be possible if optical, radio, x-ray, and extreme ultraviolet data were available simultaneously. Studies of the pre-eruptive optical flare phenomena were successfully completed using SOON data; the results are applicable to the SOON observing sequences.

The relationship between locations of sheared magnetic fields and sites of major flare activity is being investigated through in-house and contractual efforts, using both theoretical magneto-hydrodynamic (MHD) models and direct observations of vector magnetic fields, chromospheric geometry, and photospheric velocity fields. The association between flares and magnetic shear is well established, and is readily interpreted by the MHD models in terms of energy storage in field-aligned currents driven by translational motions of the underlying photospheric gases. Calculations show that storage of energy sufficient to account for a major flare (10E32 erg) can be accommodated in fields of approximately 1000 Gauss, in a volume appropriate to the observed physi-



Motions of individual sunspots are shown at the left, where a sunspot (the hatched area) of magnetic polarity opposite to its surroundings produces shear as a result of its oppositely directed motion. (Consequently, the orientation of the photospheric magnetic field (right) indicates a highly-sheared configuration along the polarity inversion line (heavy dashed line), where major flare activity occurred in the following several days.)

cal extent of the flare, when the fields are subjected to shearing velocities of 100-300 m per second. An example of a typical flare-active region is shown in the figure, where the motions of oppositely-poled sunspots are compared with direct measurements of the orientation of the photospheric magnetic fields. The highly inclined (sheared) magnetic fields near the polarity inversion line coincided with the location of the only major flare activity in this region during the following several days. This work has led to the formulation of "shear index" parameters, which provide a qualitative basis for predictions, and which will be applicable for inclusion in the MVDA statistics program. Generally, the observational technique is applicable to the SOON observing sequences, and will be useful in identifying locations and magnitudes of impending flare activity on time scales of approximately one day. Much additional research, at high spatial resolution, will be required in order to observe the critical degree of shear that will lead to the flare instability, or "trigger."

Solar Flare Processes: One of the major concerns of recent flare research is the transport and distribution of flare energy with depth in the solar atmosphere. This is especially important in highly energetic, particle-emitting flares, for which known energy-transport mechanisms can not account for the extremely large (10E29 erg per second) radiative losses from the deep chromosphere. Important new information on the optical spectrum of such events has been obtained at Sacramento Peak, and has led to the conclusion that ionization and recombination of hydrogen atoms is a dominant emission process in many cases. Detailed measurements of the radiative losses as a function of time have been compared with the associated hard x-ray bursts in several flares. The results show that if downward streams of high energy electrons are producing the emission in the optical continuum, then the optical source must consist of an overdense region in the solar chromosphere. The latter conclusion may be of considerable importance in the interpretation of spatially-resolved hard x-ray structures that are planned to be observed on future NASA missions.

The optical continuum in flares has been shown to originate at densities approaching 10E14 atoms per cm^3 and at temperatures on the order of 10E4°K. A diagnostic technique has been developed which allows a direct measurement of the column density of second-level hydrogen atoms in the optical continuum source. This technique is independent of atmospheric modeling parameters and provides valuable information on the vertical extent of the flare and its relationship to emission in the hydrogen Balmer lines. Additional spectroscopic studies have succeeded in measuring the intensities of many lines of neutral and ionized helium in energetic flares. These arise in temperatures 2E4 - 10E5°K. This information, when combined with measurements of the optical continuum, leads to a thermodynamic description of the lower atmosphere in the flare, and establishes important constraints on the energy transport mechanisms in the flare. The helium lines were also useful in determining the upper limit of macroscopic electric fields in the flare plasma, as might be expected to be present if magnetic field reconnection processes were occurring in the same volume. An important international scientific conference, devoted to the subject of the lower atmosphere in flares, was organized and chaired by the Solar Research Branch and held at Sacramento Peak in August, 1985.

The key to understanding solar flares, as well as other types of solar activity, lies in the evolution of the magnetic field, which permeates all layers of the solar atmosphere. Major advances in future research largely depend on improved spatial resolution of instruments and the ability to simultaneously observe field-plasma interactions at all heights in the atmosphere. In recognition of this, the Solar Research Branch has proposed the construction and flight of the Solar Activity Measurements Experiments (SAMEX), which would consist of a vector magnetograph, a hydrogen-alpha imager, and an extreme ultraviolet imager -- all observing at 0.5 arcsecond resolution. The initial portion of a concept study for SAMEX has been completed and has been briefed to the Space Test Program, NASA, and the scientific community. Design studies for the vector magnetograph, extreme ultraviolet optics, and detectors have been accomplished under contract. A related effort in setting up a prototype vector magnetograph, for ground-based observations at Sacramento Peak, is being funded under the Air Force University Research Initiative program.

Origins of Solar Activity: Improving the Air Force's ability to predict when and where activity will occur on the sun requires an understanding of the physical mechanisms that lead up to, and trigger, the activity processes. The interactions between solar magnetic fields and dynamical processes such as convection, rotation, and oscillations are the drivers of solar activity and variability. The Solar Research Branch has an active in-house and contractual research program to understand these interactions, both on the small scales important to the local build-up and release of energy in flares and on global scales that generate and drive the overall magnetic structure of the sun, leading to solar activity cycles. The past two years have seen a significant improvement in the database used for these studies because of the observations from Spacelab 2 discussed above and from application of image-enhancement techniques to ground-based observations.

The mechanisms that heat the solar atmosphere provide the energy to accelerate the solar wind, and supply the energy released in flares and other activity processes are still not understood. Waves that propagate through the solar photosphere and deposit their energy in higher atmospheric layers are one possible heating mechanism. Observing these waves from the ground is extremely difficult because image motion caused by atmospheric seeing introduces a large, random component in the solar signal. Taking advantage of the progress made in active solar imaging during the last few years, we used an agile mirror to feed a stabilized solar image into the echelle spectrograph at the Sacramento Peak vacuum tower telescope. The agile mirror is a rapidly tiltable mirror that can be locked onto a solar feature, such as a sunspot or pore, using an error signal generated by a quadrant detector. Thus, when the earth's atmosphere produces a motion of the image, the agile mirror is quickly tilted to compensate and the image passing into the spectrograph does not move. From the stabilized spectral time sequence generated in this manner, the motions in the solar atmosphere can be followed as a function of time and height. Using the agile mirror has permitted the direct measurement of the acoustic flux in the solar photosphere out to frequencies of about 40 Hz. Previous measurements made without image stabilization are cut off by the earth's atmosphere for frequencies above about 12 Hz. The measured acoustic flux is sufficient to account for the heating in the lower solar atmosphere. How this flux changes in the presence of magnetic fields and to what heights it penetrates into the atmosphere before depositing its energy is the subject of ongoing research.

To aid in interpreting the observations of solar processes, the Solar Research Branch is performing theoretical studies of the effects of motions and magnetic fields on spectral lines formed in the sun's atmosphere. Earlier work investigated the effect of monofrequency acoustic waves on solar line formation. In 1985-86 this work was extended to study numerically the effects of acoustic wave packets on solar lines and to compare analytically the effects of gravity waves and acoustic waves. The acoustic wave packets produce measurable asymmetries in the solar lines, but can not produce enough line broadening to account for the widths of the solar line profiles. Gravity waves are more efficient at broadening the solar lines. These theoretical calculations indicate that waves will produce observable effects and they permit us to interpret the observations discussed above as propagating acoustic waves. Further work is needed to make quantitative measurements of the energy flux being carried by the waves and to determine how the wave energy is converted to atmospheric heating.

High Resolution Imaging: Much of the physics leading to solar activity occurs on spatial scales that are often too small to resolve from the ground because of image degradation caused by the Earth's atmosphere. Aside from moving the telescope to space, which is costly and reduces the flexibility of the instrument, there are several ways of improving the image from the ground. The solar imaging effort has focused on the development of a real-time adaptive optics system and on post-facto speckle-imaging techniques.

Speckle imaging (SI) is a technique for recovering image information by post-facto processing of multiple high-speed exposures of the target. Three such techniques, known as the Labeyrie technique, the Knox-Thompson technique, and Speckle Masking have been investigated. While the first technique recovers the Fourier modulus (or, equivalently, the autocorrelation) of the target only, the latter two also recover Fourier phases and therefore permit "true" image reconstructions to be made.

The study of these techniques has been extremely successful. One of the major problems associated with the application of SI techniques, the proper calibration of reconstructed Fourier amplitudes without a suitable reference source, has been adequately solved by a technique that extracts information on the status of the earth's atmosphere directly from the data and then applies a suitable model transfer function to the Fourier amplitudes. The implementation of both the Knox-Thompson and the Speckle Masking techniques led to successful reconstructions of solar surface detail.

A substantial amount of data was analyzed using the Knox-Thompson technique in particular. We found that, under average seeing conditions (1.5 arc sec), resolution could be increased by a factor of 3 to 4 in the reconstructions, and essentially diffraction-limited performance (less than 0.2 arcsecond) is obtained when seeing is sub-arcsecond. By analyzing multiple sequences of frames, a time series of reconstructions could be produced which allows the study of dynamical processes at sub-arcsecond scales.

An example is shown in the figure. The picture at the top left is a typical input frame. It shows solar granulation in a 4 by 4 arcsecond field. The typical rms contrast of such a picture would be 4 percent and the distorting influence of seeing is clear-

Typical Single Exposure of Solar Surface (a); Average of 30 Frames, or Equivalence of 18 Second Exposure (b); Two Speckle Reconstructions Based on 50 Frames Each, Separated by 30 Seconds (c, d).

ly visible. The picture to the top right shows a 30 frame average, equivalent to an 18 sec exposure. Here, all information on structure smaller than roughly 1 arc sec has disappeared. The typical rms contrast of such a picture is 3 percent, indicating the loss of power in comparison to a single exposure. The two pictures at the bottom are reconstructions obtained from 50 frame averages and represent the first and the second half of a data set of 100 frames. The resolution is at the diffraction limit of the NSO vacuum tower telescope (0.16 arc sec at 585 nm). The typical rms contrast of such a reconstruction is 15 percent. Note the isolated, bright feature slightly above and to the right of the center of the reconstructions, which is just barely visible in the sample frame and is completely gone in the average picture. The difference between the two reconstructions reflects fine-structure evolution as well as errors in the image reconstruction process.

A prototype adaptive optics system incorporating a Hartmann-type wavefront sensor and a nineteen-segment active mirror has undergone extensive performance tests at the vacuum tower solar telescope at Sacramento Peak Observatory. The segmented approach avoids the crosstalk problems characteristic of continuous faceplate mirrors, offers higher bandwidth, and facilitates expansion to larger systems with more active elements. The principal drawback has been the practical difficulties encountered in achieving and maintaining the optical phasing among the segments. The technical performance of the prototype system is now relatively well understood, although the full extent of the system's ability to improve the resolution of solar images remains to be fully characterized. The system appears to have the ability to improve the quality of solar images up to the theoretical resolution (the "diffraction limit") of the host telescope over relatively small (a few arc-second) fields of view, in conformity with expectation. Surprisingly, the field of view over which partial improvement in image resolution occurs is substantially larger than standard theoretical considerations predict, suggesting that atmospheric propagation theory needs some revision. From an observational perspective, a principal attraction of the prototype system is its ability to deliver highly stable image resolution, even under less than optimal conditions. Experience with the prototype has also led to the identification of several changes and improvements to be incorporated in any next-generation adaptive optics system designed for solar imaging. Such planning is currently in progress.

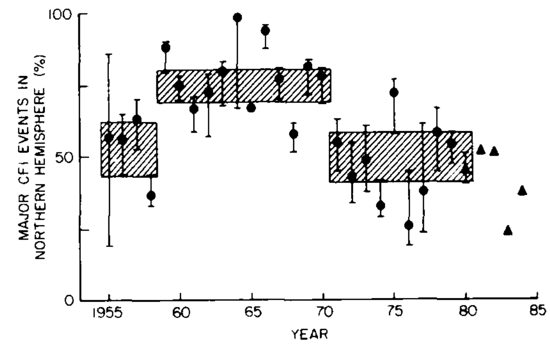
Further development of both approaches is planned. The principal attraction of adaptive optics is its ability to produce a high resolution image in real time. On the other hand, speckle imaging is technologically much simpler and less expensive to implement. Hybrid systems, which combine the power and capability of both approaches, are currently being explored.

ENERGETIC PARTICLES

The Space Physics Division is involved in many aspects of understanding how energetic particles impact on Air Force systems. The Division studies the acceleration of these particles in the sun and models their propagation through the interplanetary medium and the earth's magnetosphere, and their interaction with Air Force systems. AFGL scientists are thus constantly learning more about the space environment in which we work.

Much of the recent work at AFGL on the source of energetic particles has focused on a problem often found in solar studies: because "big" flares causing solar-particle events are accompanied by a whole host of phenomena, some of which are not causally related to the particle events, correlative studies based only on big flares can be quite misleading. To remedy this problem, AFGL scientists have examined solar events which produce significant particle fluxes but lack many other phenomena, such as microwaves and hard x-ray bursts, that often occur in proton flares. What remains after these unnecessary phenomena are stripped away will presumably be the essentials of the acceleration process. One example of this is a study of an energetic proton event which originated in a non-flare source, a disappearing filament. This showed that the electromagnetic emissions which are used as indicators of particle acceleration in flares are not essential to the acceleration. Instead, a high-speed coronal mass ejection and a shock wave seem to be the only phenomena associated with this proton event.

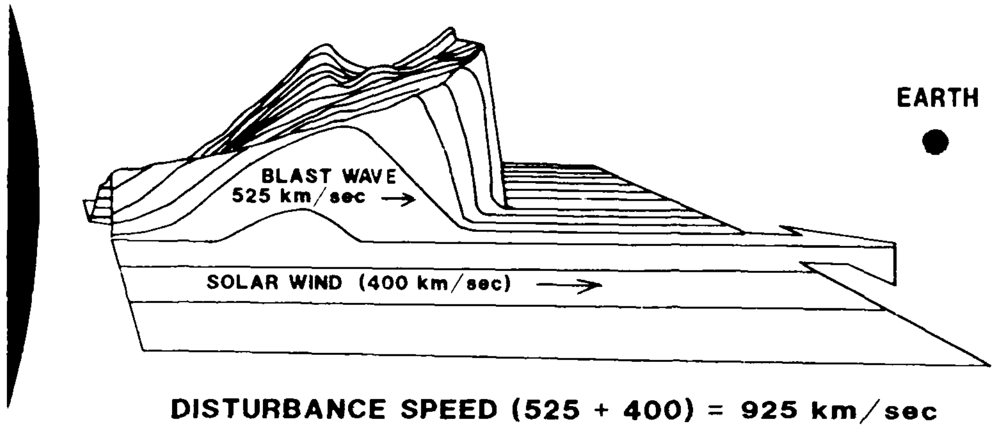
Another study examined one of the major predictors for interplanetary proton events, which is the presence of a "U-shaped" radio spectrum with high flux densities at meter and centimeter wavelengths and a minimum of densities in the decimeter range. Earlier studies showed the presence of this spectrum in a flare to be an almost necessary, and almost sufficient, condition for a major proton event. Using more complete statistics, AFGL researchers showed that the previous correlations were with phenomena physically unrelated to the particle acceleration but commonly found in flares. They discovered that the proton events are more closely associated with coronal shock waves, while the two peaks in the U-shaped spectrum are associated with different flare-acceleration processes. This work again shows that the coronal shock waves are more important for particle acceleration than the various electromagnetic phenomena.



Percentage of "Major" Flares, as Defined by the Comprehensive Flare Index, that Occurred in the Northern Hemisphere of the Sun, 1955-1980. (The triangles are preliminary data using solar flares from the six-station technique.)

Another recent study has examined a hemispheric asymmetry in the production of solar flares. Utilizing the comprehensive flare index, scientists showed that major solar activity occurred preferentially in the northern hemisphere of the sun from 1959 to 1971, although before and after this period the activity was approximately symmetric between the northern and southern hemispheres of the sun. A consistent north/south asymmetry also exists in earth-based extremely high energy cosmic radiation measurements until 1971, which is attributed to this asymmetric solar activity (see the figure).

Converting this theoretical understanding of solar particle acceleration into a predictive model of particle intensity at the earth has been approached through



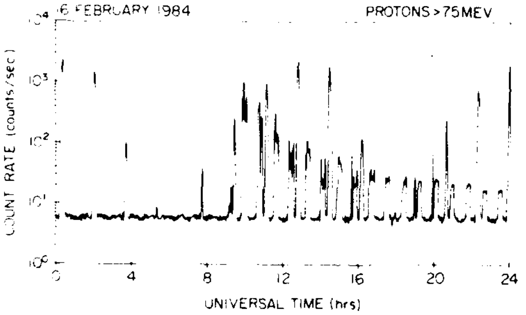
Solar induced Shock Traveling Through the Interplanetary Medium Toward Earth. (The blast wave has a speed of 525 km per second but propagates in a medium with a speed of 400 km per second (the solar wind), yielding a disturbance moving at a speed of 925 km per second toward the earth. The numbers are for illustration only; actual numbers vary from event to event.)

two methods, a magnetohydrodynamic (MHD) model and an empirical model. The MHD method models the propagation of solar flare-generated shocks, with the shock riding over the pre-existing solar wind (see the figure). In the reference frame of the solar wind, the shock front behaves as a blast wave, which continuously decelerates by giving energy up to the solar wind. The average blast-wave speed, which is found by integrating the blast wave equation, determines the arrival time of the shock at the earth. In the current two and a half dimensional model, the flare is assumed to have occurred in the plane of the ecliptic. The fluid analysis then considers all dependent variables, including the three components of the velocity and interplanetary magnetic field vectors, within the 2-dimensional ecliptic plane. A 3-dimensional model is under development.

The empirical model being developed is an improved version of the previous AFGL model which the Air Weather Service Space Environment Forecast Facility has used for the past decade. The new model has several significant improvements, such as the capability for predicting heavy ion fluxes in addition to protons. It also has improved the predictive accuracy of onset time, magnitude of fluxes, and the time-intensity profile of particle fluxes. It can also predict the radiation dose to astronauts both within the space shuttle and during extravehicular activities. The new model makes predictions in fourteen different energy ranges which are easily adjustable to match either the energies actually being monitored or those most hazardous to specific systems. It is possible to use the output of this model as input to other models designed for system-specific predictions.

In making these models, there are a tremendous number of variables that affect the solar proton intensity observed at the earth, and many of the basic control parameters are not directly observable. Instead, they must be inferred from the available solar-patrol measurements or from "average" values used in initial predictions. One major improvement is a mode which enables the duty forecaster to enter the actual observed data when it becomes known, rather than using an average or inferred value. The software then matches the specified data and uses this for updated predictions of the particle fluxes on the magnetosphere.

In the analysis of the high-energy cosmic-ray data, a method known as geomagnetic optics has been developed to specify the trajectories these particles travel before arriving at or near the earth. AFGL researchers have modeled the effect of geomagnetic disturbances on the asymptotic directions of approach by estimating the corresponding change in the cutoff rigidities.

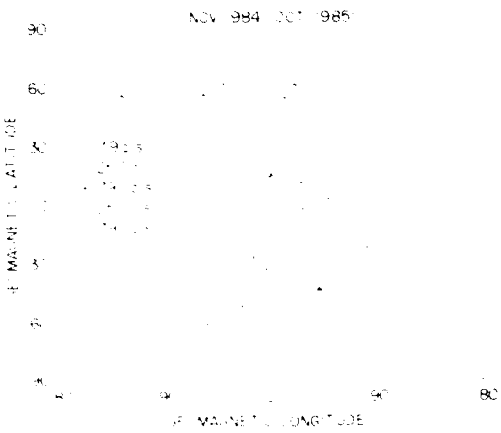


Proton Flux Counts for Energies Greater than 75 MeV Measured by the SSJ* Instrument on DMSP, February 16, 1984.

In modeling the particle environment, the particle motion and energization within the earth's magnetosphere are also significant. Several such studies have been completed using data from the Defense Meteorological Satellite Program (DMSP) satellites. The F6 and F7 spacecraft are stabilized in three axes and fly in circular, 840 km, sun-synchronous orbits. The F6 orbital plane is in the dawn-dusk meridian, while the F7 orbital plane is in the 1030-2230 meridian. Because of the offset between the geographic and magnetic poles, the two spacecraft cover a wide range in geomagnetic coordinates, and because of the operational nature of the spacecraft, they return data from the instruments almost continuously (see the figure).

One of the scientific instruments carried on F7 is a dosimeter measuring electron and ion fluxes above 40 MeV. These are the particles responsible for single event upsets and radiation effects in electronics. The spatial distribution of high-energy particles penetrating to low altitudes has been determined. The particles most responsible for single event upsets in low-altitude orbit are trapped protons in the South Atlantic Anomaly and cosmic rays in the polar caps. The trapped protons in the South Atlantic Anomaly have a much softer spectrum than the heavier particles. These results will permit the development of improved shielding for spacecraft microelectronics and improved hardening against single event upsets.

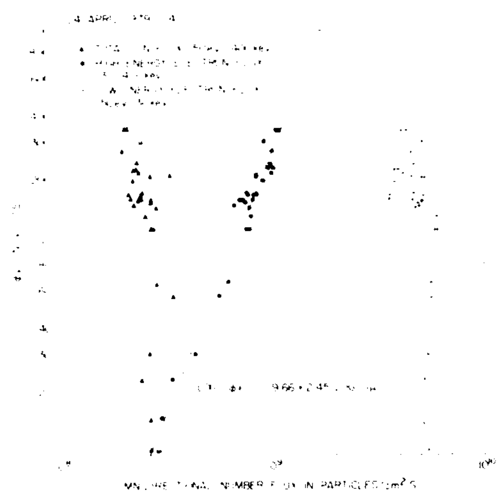
The particles at the energies primarily responsible for auroral precipitation have been studied using the SSJ/4 instruments which are both the F6 and F7 spacecraft. These instruments measure the precipitating electron and ion fluxes over an energy range of 30 eV to 30 keV and return a complete spectrum every second. Several statistical studies have been completed using the SSJ/4 data, all of which characterize the average patterns of auroral electron and ion precipitation as functions of magnetic local time (MLT), magnetic latitude (MLAT), and magnetic activity as measured by Kp. These statistics throw light on important processes controlling



Contours of Constant Dose Rate for the Electrons >2.5 MeV Lole Channel, Plotted in Corrected Geomagnetic Latitude and Longitude Coordinates.

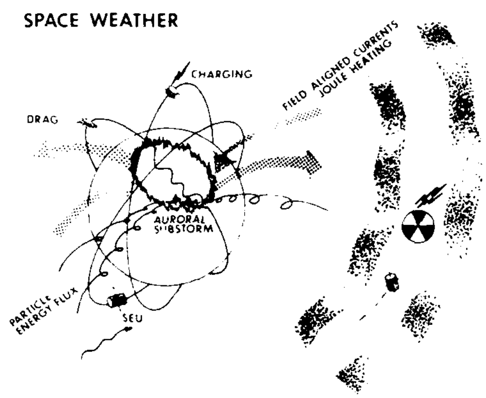
particle entry and energization. For example, these statistics provide an excellent map of the ion cusp, a direct entry region on the dayside of the earth, centered at local noon at all activities. The peak in number flux is found at lower latitudes than the minimum in average energy, and the cusp is much larger and clearer in the summer pole than in the winter pole. These results are being used in understanding the direct entry of particles from the solar wind (see the figure).

These statistics can also provide useful input to models of the environment. For example, the average electron number and energy fluxes were used to develop a model of the ionospheric conductivity as a function of geomagnetic activity. In some additional work, the equatorward boundary of auroral electron and ion precipitation was fitted to various functional forms, depending on geomagnetic activity. If the boundary is observed at some local time and the magnetic activity is known, then the boundary at all local times can be calculated, and the conductivity statistics can indicate where high-frequency radio systems are likely to fail. AFGL has delivered a computer model carrying out these predictions to Global Weather Central, allowing the Air Force to anticipate and better understand the real time impact of the aurora on Air Force communications.



Frame Potential of SCATHA Spacecraft Plotted as a Function of Omnidirectional Fluxes for Ions (triangles), High-Energy Electrons (dots), and Low-energy Electrons (crosses), Showing the Correlation of Potential with High-energy Electron Flux.

The studies described above concentrate on a better understanding of the environment in which space systems operate. However, it is also important to understand how the systems interact with the environment. One recent study examined high-level spacecraft charging in the ionosphere, showing that low-altitude spacecraft can charge to <-100 Volts, but only when two conditions are met: the thermal plasma density must be less than 10^4 cm^{-3}, and a high number flux of high-energy electrons (at least 14 keV) is required. These conditions are often met on the nightside of the earth and on the poleward edge of discrete auroral regions, so that spacecraft traveling through this region must be designed to minimize the effects of spacecraft charging (see the figure).



Space Weather Impacts on Satellite Operations.

One of the major programs under development, known as CRRES (Combined Release and Radiation Effects Satellite), will study the effects of sustained radiation exposure on spacecraft microelectronics. Current designs for space systems are based on computer models and laboratory testing of electronics, but not on in-flight testing. To remedy this, AFGL is preparing CRRES, which will carry a package of sensitive microelectronics (the MEP) carefully instrumented to study when and how the components fail. Along with this, CRRES will carry an assortment of instruments to measure the particle and electromagnetic environment in which the components fail. Comparison of these results with laboratory testing and simulations will then allow engineers to develop better and more reliable electronic space systems.

SPACE WEATHER

The specification, monitoring, and prediction of particles, plasma, and electric and magnetic fields and waves within the solar-terrestrial system is of growing importance to Air Force space operations. The dynamic characteristics of these space environment parameters which specify the coupling between regions, the resulting transport of energy, and the interaction effects of the environment with space systems is commonly referred to as "space weather." Space weather can be the cause of operational anomalies resulting from spacecraft charging, such as single event upsets, radiation effects, and increases in satellite drag. The figure illustrates these effects. Satellites at all altitudes are subject to space weather effects.

The thrusts of the program are directed toward (1) greatly expanding the space environment database, (2) developing and testing empirical models of the physical parameters essential to the understanding of the coupling processes between solar-terrestrial regions, and (3) developing dynamic analytical models of the interplanetary/magnetosphere/ionosphere system that include the time variability of these solar-driven processes. This result is essential to advances in understanding, specifying, and predicting the space environment and its effect on Air Force space systems.

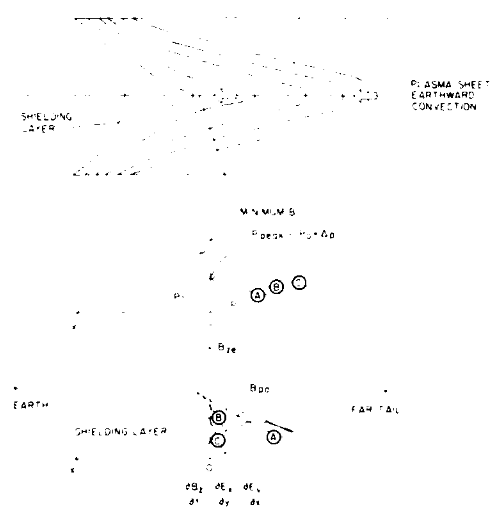
Extensive measurements of particles, plasmas, and fields have been obtained from orbiting satellites such as DMSP, HILAT, and DE in the last few years. However, the vastness of regions, the sparseness of the data, and the short- and long-term solar variations cause our understanding of the physical system to be limited by data starvation. On the DMSP spacecraft, continuous monitoring of particles, electric and magnetic fields, and plasmas with instruments designed and developed by the Space Physics Division represents a major contribution to the space environment database. Significant progress has been made in specifying the coupling between the magnetosphere and the ionosphere and in modeling the dynamics of the inner magnetosphere. As a result, models are now under development w' .h specify the magnetosphere for operational use by the Air Weather Service in response to customer requirements. The following highlight specific research progress.

Magnetospheric Specification: Specification of the environment at high latitudes and throughout the magnetosphere provides the foundation for empirical theoretical studies and modeling of space weather processes. The operational DMSP satellites provide a unique opportunity for long-term monitoring of critical parameters. Continuous monitoring of the energy input from the magnetosphere into the high-latitude ionosphere, both from particles and from heating by closure of field-aligned currents, will now be possible.

In cooperation with the University of Texas at Dallas, instruments have been designed and built to monitor ion drift (electric fields), ion density and temperature, electron temperature, and variations in ion density which are the cause of radio scintillations. The first of the instruments will be flown on the next spacecraft.

Analysis of data from the experimental magnetometer on DMSP-F7 has determined that a body-mounted magnetometer can be used to detect field-aligned currents. Automated techniques were developed to remove spacecraft interference signals from the data, leaving the variations caused by the field-aligned currents. As a result of this successful experiment, the magnetometer will be included as an operational sensor on future DMSP satellites S-12 through S-15. The DMSP plasma, magnetic-field, and energetic-particle measuring devices provide complete local specification of the electrodynamics. The combination of the electric fields, field-aligned currents, and conductivities (calculated from the particle data) determine the heating input into the high latitudes from magnetospheric sources.

Plasma and fields instrumentation has also been designed and built for the CRRES satellite. In addition to supporting the radiation-effect studies, these instruments will be a significant new source of data for understanding the dynamics of substorm processes.



Mechanism for Generating Neutral Lines in Near-Earth Magnetotail, a Process Thought to Trigger Substorms.

Magnetospheric Modeling: AFGL has previously sponsored the development at Rice University of a dynamic analytical model of the inner magnetosphere to specify and follow substorm processes in the coupled magnetosphere-ionosphere system. This model has been reformatted to make it more modular, to increase its efficiency, and to add in effects from the near-tail plasma sheet. In the space physics community, a strong controversy exists over whether a near-earth neutral line can form and create a magnetic substorm. As a result of the improved model, a straightforward mechanism for the formation of a near-earth neutral line has been developed. The accompanying figure illustrates these ideas.

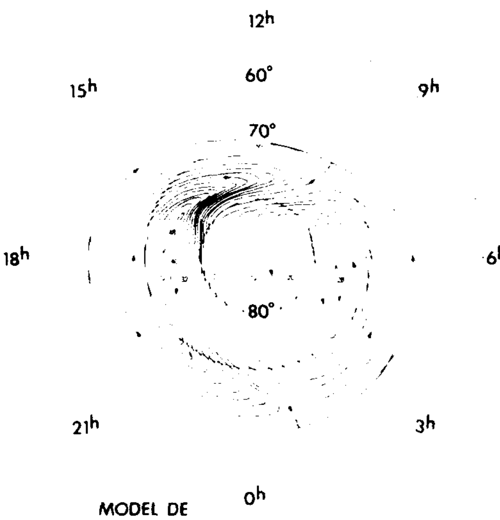
The top figure is a north-south cross-section of the midnight meridian at L greater than, or equal to, 6. The dawn-dusk electric field causes plasma to E-x-B-drift towards the earth as shown by the arrows. As the attached magnetic flux tubes convect inward, their volume decreases, thereby adiabatically increasing particle pressure, as seen in the middle figure. Cases A, B, and C are for increasing E-x-B drift. The associated pressure gradients create a local current that produces a minimum B along the equator as seen in the bottom figure. Magnetohydrodynamic computer simulation studies indicate that this is the most likely location for magnetic reconnection to occur. A non-zero curl of E triggers the instability for reconnection to occur. Magnetic reconnection prevents the continual build-up of particle pressure and releases excess magnetic energy stored in the tail-lobes. In this model, a magnetic substorm occurs as a natural result of excess particle pressure, and an external stimulus is not necessary to trigger it.

The Rice model is an important building block toward the development of models for space weather specification and forecasting for use by the Air Weather Service. Portions of the research model are now being transitioned to AWS for magnetospheric specifications. Future improvements in the model and in our modeling capabilities will be directed toward better specification of the ionospheric boundary conditions and coupling processes, and toward better understanding of boundary layer phenomena in the plasma sheet and at the magnetopause.

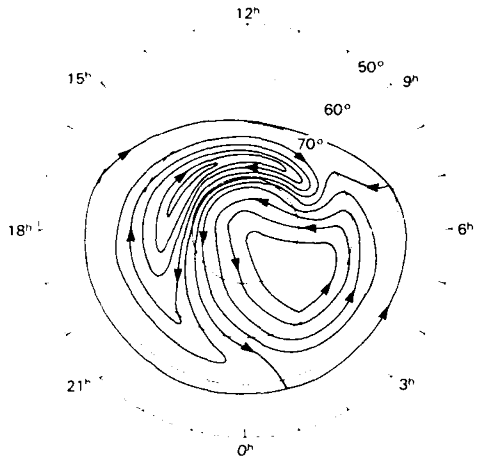
Magnetosphere - Ionosphere Coupling: The plasma drift measurements on the HILAT satellite, the magnetic field measurements on the DMSP/F7 satellite, and the electric field measurements from DE-2 have proved to be powerful tools for analysis of magnetosphere-ionosphere coupling processes.

In a study aimed at finding general magnetosphere-ionosphere coupling characteristics instead of just the coupling related to direct auroral arcs, SRI International, AFGL, and the University of Texas at Dallas statistically determined the relationships between the variations in the electric field and field aligned current in the range of scales of 3 km to 80 km (approximately the range of "inverted - V" structures) observed during the first year of HILAT's life. This study included all structures in this scale range regardless of the precipitating particle signature. The result was a clear indication that in this scale-size range the magnetosphere acts as a constant current source regardless of the background conductivity of the ionosphere. Further study using particle data together with the electric field and current data will be required to confirm this finding.

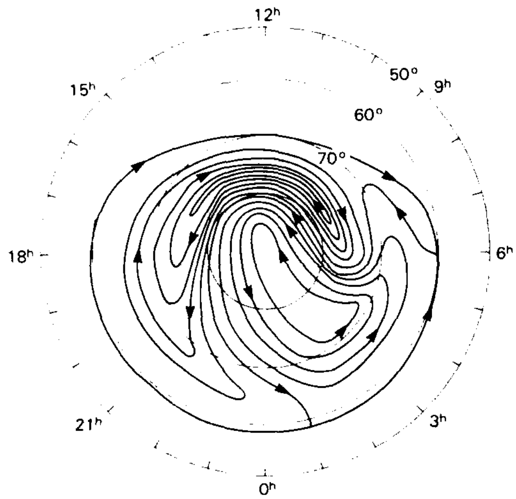
On the scale size of individual arcs, Regis College and AFGL analyzed in detail an individual pass of the HILAT satellite over an isolated, morning-sector auroral arc. The study included all sources of data from the HILAT satellite and the ultraviolet imager, which can detect the auroral arcs during the sunlit condition. The object of the study was to characterize the physical structure of the arc system and compare the structure with the coupled electrodynamic theory of Bostrom for auroral arcs. The comparison was excellent. Since a numerical model of an arc structure developed by the University of California at Berkeley has been based on Bostrom's theory, advancements in numerical simulation of arcs can now be made with confidence.



(a)



(b)



(c)

Empirical High-Latitude Convection Models for Magnetospherically Generated Electric Fields. (The plots are for the northern hemisphere, with the Y-component of the interplanetary magnetic field negative. The first panel is for a southward B_z and a small northward B_z. The second and third are for increasingly stronger northward B_z.)

F-region ion convection in the vicinity of the dayside polar cleft is strongly controlled by the interplanetary magnetic field, suggesting a direct current-driven coupling between the solar wind and dayside, high-latitude ionosphere. This coupling has been explored by Stanford University through observations of high-latitude ion convection measured by the Sondrestromfjord, Greenland, incoherent scatter radar and subsequent computer simulations. The computer simulation calculates the ionospheric electric potential distribution for a given configuration of field-aligned currents and conductivity distribution. Using a simple model of the field-aligned currents linking the solar wind with the dayside, high-latitude ionosphere, we can explore the consequences of variations of the currents on ionospheric plasma convection. The direction and strength of the currents are set according to measurements in the upstream solar wind, and the time-varying ionospheric electric field and resulting plasma convection are simulated. Comparisons of the simulated plasma convection with the ion velocity measurements at Sondrestrom show very good agreement.

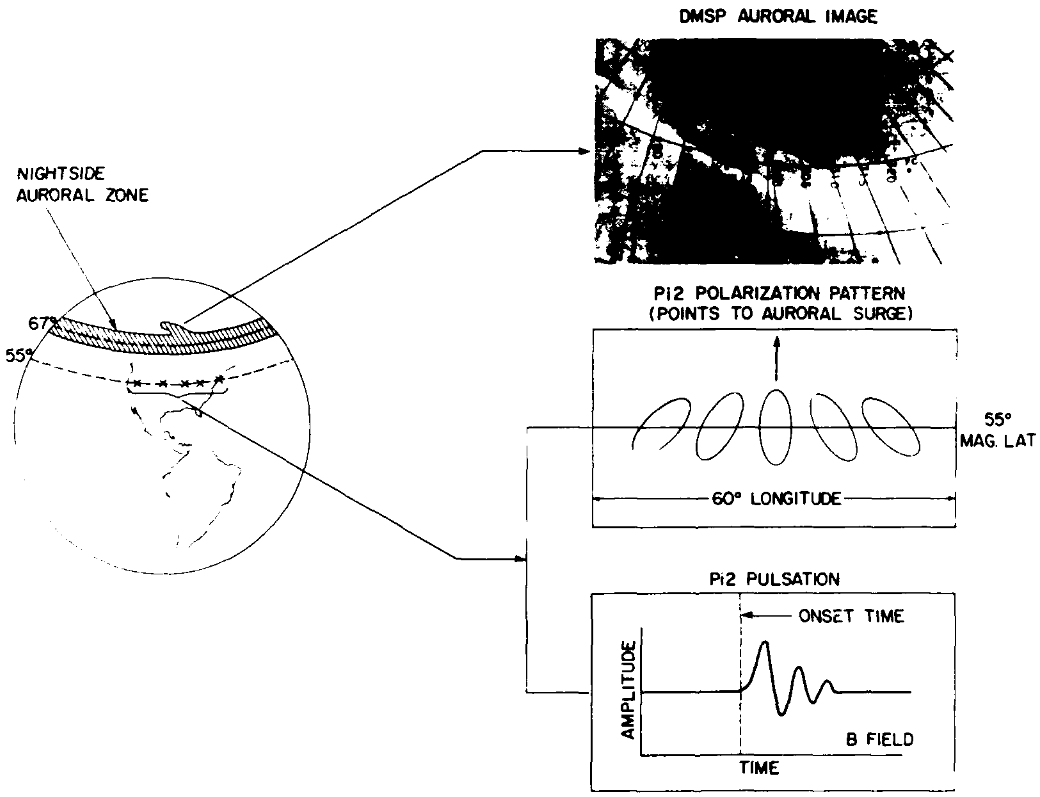
New empirical models of the overall high-latitude convection pattern generated by magnetospheric electric fields and their variation with the interplanetary magnetic field have been developed using DE-2 data by NASA/GSFC and AFGL. Preliminary versions of the variations of the patterns with the polarity of B_y for southward B_z have been used in the University College, London, global thermospheric model to provide better agreement with observations of neutral winds, temperature, and composition. The basic models for positive and negative B_y are applicable for B_z negative and for small values of positive B_z. As B_z increases to larger positive values, the evening convection cell rotates and expands into the dayside, creating a distorted two-cell model. The figure shows the basic northern hemisphere convection flow pattern for B_y negative (model DE) and its distortion as B_z increases to larger and larger positive values. For B_y positive, the evening cell rotates into, rather than around, the morning cell. These patterns provide a new alternative to the three- and four-cell pattern currently used to explain configuration changes in the convection pattern for northward (positive) B_z conditions.

Modeling and Analysis of Substorm Phenomena: The datab. . created by the AFGL magnetometer chain from 1978 through 1983 continues to be a significant resource for analysis of substorm-associated processes and their resulting magnetic pulsations. The correlation of effects recorded by the AFGL chain with signatures seen at geosynchronous altitude by satellites such as GOES and SCATHA, or signatures noted at the South Pole, are revealing the character and evolution of magnetospheric substorm disturbances.

For instance, the disturbances at geosynchronous orbit may be very localized. By observing the effects of the substorm current wedge on the ground to identify the onset and location of a substorm, AFGL and Boston University scientists were able to show that a geosynchronous satellite (GOES 3) only two hours away from midnight may miss the onset of a localized substorm. The character of the GOES-3 magnetic disturbance was nearly flat compared to the disturbed signature seen two hours away in the substorm wedge region near midnight by SCATHA and GOES 2. Observations made with the AFGL chain, at South Pole station, and from the ISEE satellites demonstrated that the thickening (or recovery) of the magnetotail plasma sheet during the late stage of substorms is related to poleward auroral excursions, sometimes called the "poleward leap," contributing to a relatively little studied aspect of the neutral line model of substorms.

Pi 2 pulsations have been previously associated with substorm onset; however, the generation mechanisms that would produce the observed polarization characteristics were unclear. The extension of the previous model for the westward traveling surge developed at AFGL has shown that Alfven waves, initiated by the injection of hot plasma-sheet electrons within the substorm current wedge, trigger a feedback instability in the ionosphere-magnetosphere system that leads to the rapid production of the Pi 2 waves. The pulsations are then damped by electron-ion recombination. The model also provides the framework for understanding the sense of rotation of Pi 2 pulsations generated at substorm onset.

The relationship between mid-latitude magnetic disturbances and the westward traveling surge has been explored further by using DMSP images. The figure shows the concept for location determination of the westward traveling surge from mid-latitudes. Actual events have been correlated between DMSP photographs and patterns observed in the magnetic polar-



Location of Auroral Surges Using Mid-latitude Magnetometer Pi2 Pulsation Signals. (The major axis of the polarization ellipse points toward the center of the surge. The pulsation onset time identifies the substorm's onset.)

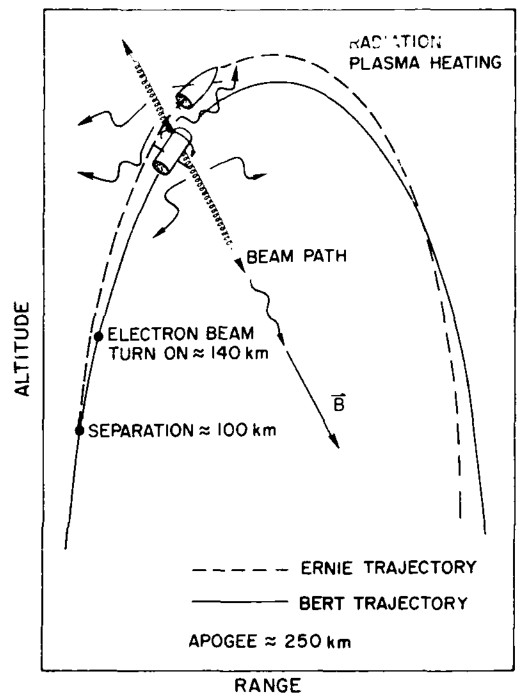
ization ellipse azimuths observed by the AFGL chain.

ACTIVE EXPERIMENTS

The Active Experiments Branch of the Space Physics Division carries out experimental and theoretical investigations of controlled perturbations in space with two objectives. The first is to test our understanding of space plasma processes and their effects on space systems. Some of these processes may be stimulated by charged particle beams, waves, or chemical clouds. The Branch is investigating the generation of plasma waves in space, the heating and acceleration of electrons and ions in the ionosphere/magnetosphere system, the release of substorm energy, and the trapping of particles in, and their precipitation from, the earth's radiation belts. The second objective is to consider the perturbations as part of a complete system which includes the space vehicle, the perturbing agent, and the space environment. There are interactions between the elements of the system that may inhibit particular processes. Some of these interactions are: arcing and charging in the vehicle environment, anomalous beam degradation, and disruption of wave transmissions.

There are four major areas of study: charged particle beam/environment interactions, neutral particle-beam transport, effects of electromagnetic radiation on space plasmas, and chemical releases in the magnetosphere.

Charged Particle Beams: Artificial beam propagation in space generates waves that heat and accelerate ions and electrons in the ambient plasma. Naturally occurring charged-particle beams generate similar effects which have been observed on numerous rocket and satellite experiments. Electron beam emissions have been found to generate waves that heat and accelerate ambient ions in processes similar to those identified in theoretical models that explain auroral particle-acceleration processes. Experiments are planned to verify these models.

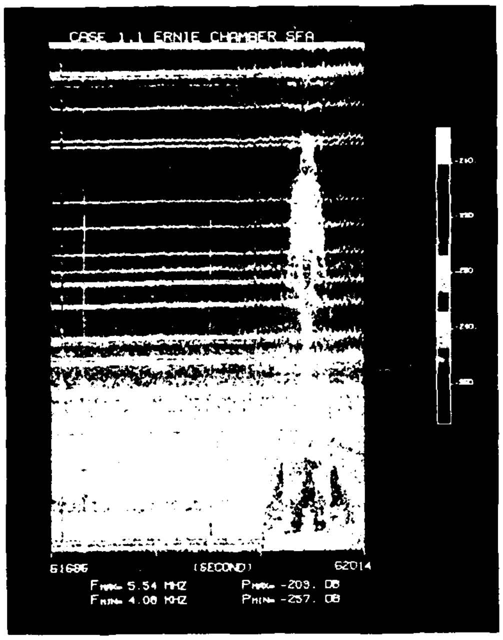


The BERT-1 rocket consisted of two separable payloads. The main body of the rocket, BERT, was equipped with electron, ion, and plasma emitters, an automatic discharge system, vehicle potential monitors, and particle detectors. The nosecone, ERNIE, was separated from the main payload during flight. It was equipped with plasma and field diagnostics for detecting perturbations in the ambient plasma during charged particle emissions from BERT The electron beam generates waves, and heats and accelerates electrons and ions in the ambient plasma.

Data being analyzed include SCATHA satellite experiments in the magnetosphere and BERT-1 rocket experiments in the ionosphere and in a large vacuum chamber (see the figure). Both SCATHA and BERT-1 vehicles were equipped with ion and electron beam sources, used to study vehicle-charging effects as well as beam/plasma interactions. Charging of spacecraft, which occurs naturally in space environments containing energetic particles, may be controlled through beam emissions. However, beam emissions may also cause charging, under certain conditions. The plasma processes that control vehicle-charging levels are being studied.

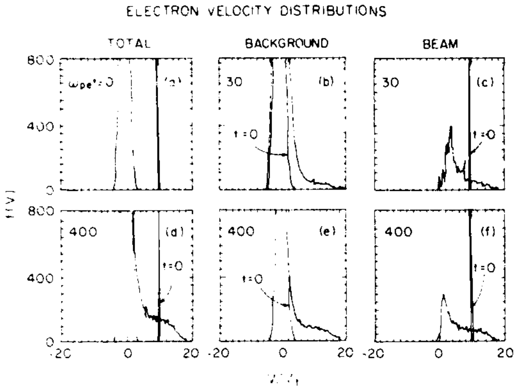
Theoretical studies are being conducted in collaboration with the University of California at Los Angeles and with Southwest Research Institute. These studies incorporate theory and computer simulations in mock laboratory experiments to identify mechanisms leading to effects observed in the data. Present studies have provided new insight into processes controlling vehicle charging. Beam-generated waves are shown to heat the ambient plasma, which enhances the rate of ionization of ambient neutral particles (see the figure). This increases the plasma density and reduces the potential of the vehicle charging.

The Active Experiments Branch is conducting the ECHO-7 sounding rocket experiment jointly with NASA and the University of Minnesota. The branch is building a 40 keV electron accelerator system and a wave detector package for the mission. Mission objectives are to study wave generation in the ionosphere and spacecraft charging due to electron beam emission. The experiment will also probe the magnetosphere by emitting electron beams along the earth's magnetic field and detecting the return of beam particles after they are reflected from the conjugate ionosphere.



Experimental results obtained during the BERT-1 vacuum chamber tests indicate high-frequency, high-intensity waves being generated during electron beam emissions. (The spectrogram scales linearly with frequency from 0-5 MHz. The electron beam energy is 500 V and is stepping up, then down, through current levels of 200 μA to 20 mA. As the beam current increases, there is a threshold effect, indicated by the appearance of intense waves in the 3-4 MHz range. This coincides with a sudden decrease in the potential of the emitting rocket body. The potential then maintains a constant level until the current decreases across this threshold, at which point the potential abruptly increases.)

Neutral Particle Beams: Unlike charged particle beams, neutral beams can propagate across vast regions of space without being deflected by the earth's magnetic field. However, if the beam were ionized by the earth's tenuous plasma, this would also be subject to deflection by the magnetic field. Theory and laboratory experiments have shown that such a plasma beam will propagate across a magnetic field in a vacuum, but



Results of Computer Simulations at UCLA Showing Beam Thermalization and Beam Heating and Acceleration of the Ambient Plasma. (This is part of a study to determine the characteristics and signatures of electron beams propagating in space.)

the question of whether it will propagate in a plasma has not been answered. To answer this question, laboratory experiments are being performed in collaboration with Northeastern University. These experiments will explore the effectiveness of polarization electric fields for crossfield propagation. Parameters to be studied include: geomagnetic field strength, beam orientation with respect to the magnetic field, and ambient plasma density. In addition, beam degradation due to waves and heating generated by interactions with the ambient plasma will be investigated.

This experimental program includes the design and development of a wave diagnostics package for the AFSTC NPBISE (Neutral Particle Beam Integrated Space Experiment). This package will monitor waves and fields generated in the ambient plasma through the propagation and ionization of the neutral beam. Related theoretical studies are seeking to predict electromagnetic signatures of the ionized portion of the beam, as well as to anticipate effects of the beam emission on the spacecraft.

Electromagnetic Radiation: The ability of electromagnetic radiation to accelerate particles in the natural environment is being investigated under Project Forecast 2. It has been shown theoretically that rf radiation directed along the background magnetic field in a vacuum will accelerate electrons to relativistic energies.

A new theory developed in collaboration with Northeastern University predicts that a high power (gigawatt) transmitter, tuned to the resonant frequency of the ionosphere, should succeed in accelerating electrons to a broad range of energies. An experiment to test this concept is planned in conjunction with the ECHO-7 flight. HIPAS (High Power Auroral Stimulation facility), a ground-based transmitter located below the rocket trajectory, will transmit waves at the resonant electron gyrofrequency. Sensors on the ECHO-7 payload will detect the transmitted waves and the accelerated electrons. A computer model of the acceleration process is being developed. This model will be tested with the experimental results obtained during this flight.

A second theoretical effort concerns the application of the Alfven maser effect to cause particle precipitation in the radiation belts. Similar to an ordinary laser, pump waves can be beamed into the magnetosphere and built up within magnetic flux tubes there. It is believed that this energy can be used to dump plasma through loss cone diffusion. Experiments will be designed to test this theory.

Chemical Releases: Chemicals introduced into the magnetosphere can generate and undergo a variety of interactions with ambient waves and particles. High-altitude chemical-release experiments are planned as part of the CRRES satellite program. The experiments are designed to study these interactions and the effect of mass loading of magnetic flux tubes. Plasma and field diagnostics are being provided for this purpose. Data from the experiments will be analyzed to establish the conditions that lead to the dumping of radiation belt particles. Theoretical models being developed in collaboration with Massachusetts Technological Laboratories will be used to predict these interactions.

Spacecraft Contamination Modeling - SOCRATES (Shuttle Orbiter Contamination Representation Accounting for Transient Emitted Species) Code.

SPACECRAFT ENVIRONMENTAL INTERACTIONS

Shuttle Contamination Code (SOCRATES): The development of a shuttle contamination code called SOCRATES, an acronym for Shuttle Orbiter Contamination Representation Accounting for Transient Emitted Species, was initiated using Monte Carlo techniques. Contamination of instruments on the space shuttle orbiter is an issue of major concern. The shuttle gives off matter through surface outgassing, via various thrusters and from flash evaporators.

The deposition back onto shuttle-borne instruments will be largely determined by the multiple collision environment surrounding the shuttle (see the figure). In addition to physical contamination of surfaces, radiation contamination occurs as gases surrounding the shuttle collide with atmospheric ions, electrons and molecules, and with the shuttle surfaces. In addition, the critical ionization-velocity effect may be important in the enhancement and transport of contaminant species. Once critical ionization occurs, molecular dissociative recombination may follow. These effects may lead to characteristic infrared, ultraviolet, and visible radiation in the vicinity of the space shuttle.

The SOCRATES code is being designed in a highly modularized fashion, so that additional physical and geometric complexity can be added as deemed necessary without requiring major rewriting of the model. SOCRATES now treats plume modeling and exhaust flow-field computations. Eventually, it will be employed for computer simulation analysis by incorporating critical ionization effects, surface chemical reactions, charged particle transport, molecular dissociative recombinations, and radiation contamination.

Shuttle Particulate Contamination Measurements: The particulate environment surrounding the shuttle during Mission 61-C in January, 1986, was observed using a pair of cameras mounted in a stereoscopic configuration. In addition to solar-illumination, a strobe flash unit was used to provide illumination so that particulates could be observed during orbital night. Data was acquired throughout the mission. Although events such as water dumps, maneuvers, satellite launches and payload bay door operations, and even the orbital environment, were often found to be very benign, there were times when contamination was severe (see the "bliz-

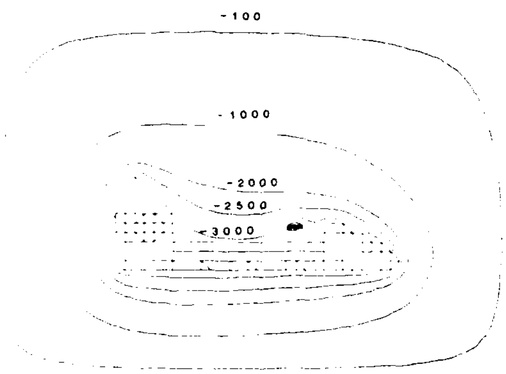
Shuttle Particulate Contamination Measurements.

zard-like" contamination distribution in the figure).

The program goal is to develop guidelines for specifying when the environment will be acceptable to perform shuttle-based optical measurements. Particles were observed even during periods when all operations (and maneuvers) were disabled. Nearly 15,000 frames of data were acquired over 83 orbits. The key observational parameter was solar scattering angle. Particles were observed about 40 percent of the time when illumination conditions were optimal. Particle angular velocities were obtained from a series of sequential exposures. Source locations have now been tentatively identified and the observations have been analyzed in light of Mie scattering calculations in order to estimate particle characteristics and to assess impacts in other sensing bandpasses, especially the infrared.

Shuttle Glow: A glow, or halo, has been observed off surfaces of the space shuttle when those surfaces are in the ram direction. On some flights the glow was visible to the naked eye. The observations to date have been made with hand-held cameras from the astronauts' cabin. These observations indicate that: the glow extends about 20 cm beyond the surface; its spectrum is nearly a continuum with a maximum at about 600 nm; it depends, to some extent, on the chemical composition of the surface; it is strongly influenced by the firing of thruster engines; and its intensity depends on the altitude. Analysis of photometric data from Atmospheric Explorer (AE) and Dynamic Explorer (DE) satellites indicates that the glow is a general phenomenon associated with all spacecraft in low earth density. Infrared and ultraviolet data are needed. Current interpretation of the origin of the glow suggests that it is caused by nitrogen dioxide, NO_2, formed by a complex sequence of chemical reactions between the ambient atmospheric species (nearly 70 percent of which are oxygen atoms) and the shuttle surfaces in the ram direction. The shuttle velocity is approximately 7.3 km per sec (corresponding to an energy of 4.4 eV). Support for this theory has been obtained from our analysis of mass spectrometer data, which indicates that NO_2 is present in sufficient quantities to cause the glow.

Spacecraft Charging: The centerpiece of our interactions modeling program is the three-dimensional simulation code POLAR (Potentials of a Large Object in the Auroral Region). The POLAR code simulates in three dimensions the electrical interaction of the shuttle or any space vehicle with the space plasma. It models the physical processes of wake generation, ambient ion collection, effects of precipitating auroral electron fluxes, surface interactions including secondary electron generation and backscattering, and vehicle charging (see the figure).



POTENTIAL CONTOURS, VOLTS

Spacecraft Charging.

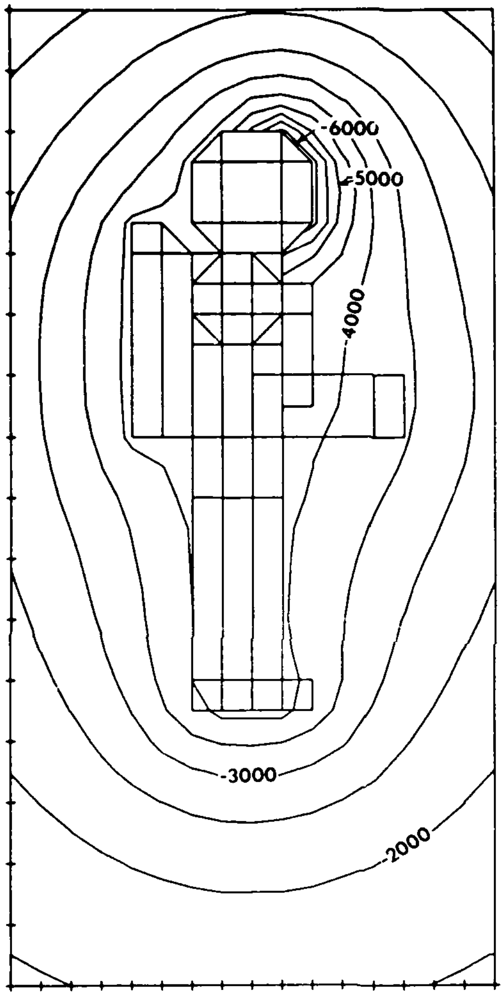
The code follows these processes dynamically on a subsecond timescale so as to simulate the shuttle's rapid passage through intense auroral arcs or the emission of charged particles. POLAR models the ambient plasma as isotropic Maxwellian electrons and ions and allows for simultaneous precipitation of power-law, energetic Maxwellian and accelerated Gaussian distributions of electrons. Geomagnetic field effects are included in particle dynamics and conductor potentials. POLAR computes charging in the low-altitude space environment for individual portions of a vehicle's surface. It does so by tracking ambient ram ions through the plasma sheath and wake surrounding the vehicle, computing the incident auroral electron flux, updating individual surface potentials, and solving Poisson's equation self-consistently with computed space charge densities.

POLAR is now installed on a dedicated super-mini computer, and in-house efforts have expanded to include applications of POLAR, validation studies, comparison with flight data, and separate numerical studies. Electrical charging of spacecraft by intense 10 keV auroral electron streams to high negative potentials has been observed on DMSP (Defense Meteorological Satellite Program) satellite spacecraft. POLAR has scored initial success in modeling the auroral charging of an idealized spacecraft, and studies using a detailed representation of a DMSP craft are now underway.

Interactions theory predicts that auroral charging is more dramatic for larger vehicles such as the shuttle, even in the low altitude space environment. A negatively charged vehicle collects positive ions through a plasma sheath whose thickness is proportional to potential and roughly independent of vehicle size, so that the potential must increase in magnitude for the sheath to scale with spacecraft size. Modeling with POLAR has confirmed this theoretical prediction and demonstrated that charging potential scales as the 4/3 power of the vehicle size. POLAR has further demonstrated that this scaling relation is modified by the secondary emission properties of the surface materials.

As with the size effect, access to ions is the key to other auroral charging events that occur when small subsatellites such as the astronaut's MMU (Manned Maneuvering Unit) operate in regions of local ion depletion such as the shuttle wake, or the sheath of another charged object. POLAR has been used to model a MMU-shuttle wake scenario and, again, confirmed quantified predictions. These results are illustrated in the figure.

EVA ASTRONAUT POTENTIAL CONTOURS



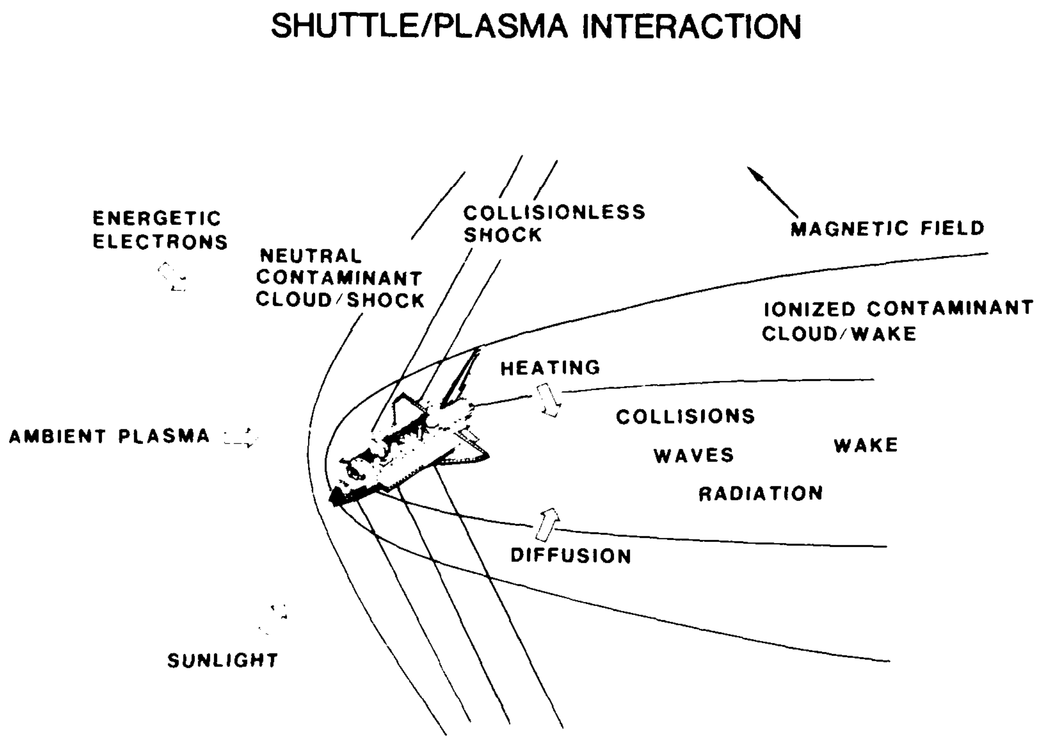
SIDE VIEW

POLAR Code Calculation of Charging Experienced by Astronaut Operating a Manned Maneuvering Unit in Ion Wake.

The MACH (Mesothermal Auroral Charging) code was developed at AFGL to independently validate the physics in POLAR, and to simulate space-probe interactions with well-known physics. MACH treats cylindrically symmetric vehicles by inside-out particle-tracking techniques. Cycles of particle tracking and potential solving converge to a self-consistent solution in which the details of the physics, particle tracking, and potential solving are well understood. The heuristic algorithms in POLAR, which make possible three-dimensional solutions for complex bodies in a short time, are validated by MACH for simpler geometries. In this way the limits of validity of the POLAR code are obtained. MACH is employed independently as well, to study the kinetic details of a plasma sheath-wake interaction, confirming that under most circumstances a sheath edge can exist in a high MACH flow wake.

Plasma Generation by Critical Ionization Velocity: The Critical Ionization Velocity (CIV) theory was proposed to explain how matter accreted during the formation of the solar system. This theory postulates that atoms are ionized when their velocity reaches a value such that their kinetic energies are equal to their ionization potential. Six space experiments have been conducted in order to confirm the theory; of these, only one gave positive results. Analysis in our laboratory has suggested a unique experiment which will establish the occurrence of CIV in space. In addition, we have established a definitive diagnostic measurement which will identify whether or not CIV has taken place. The question is very important for a number of applications, one of which is the circumstance under which the exhaust of a space vehicle in low earth orbit will become ionized. If ionization does occur, for example in the exhaust of the space shuttle engines, then the resulting ions will be trapped in the earth's magnetic field and will separate from the neutral plumes, giving rise to an extended source of radiation. This is important for any application which involves the measurement of radiation from low earth-orbit platforms.

Plasma Wave Field of Spacecraft: The shuttle and other low-altitude spacecraft move through a plasma with a number density on the order of 10^5 cm^{-3}. The interaction of the spacecraft with this ambient plasma can lead to waves and shock-like structures (see the figure). The importance of the waves is that they contribute to a complex environment in the neighborhood of the spacecraft, interacting with ions of ambient and spacecraft origins, and may provide a plasma signature detectable at large distances from the spacecraft. The propagation of waves to large distances is associated with the strongly anisotropic character of the phase and group velocities of cold plasma waves in three regimes: Alfven waves, whistlers, and upper hybrid waves. The first two regimes, which are likely to be the most important, are characterized by vanishing of the phase velocity perpendicular to the field and the presence of real spatial characteristics associated with the propagation of discontinuities. Analysis has shown that these waves, unlike those in other regimes, propagate essentially undamped within a cone around the field extending from the source. These waves



Plasma Wave Field of Spacecraft.

have been understood in the low frequency approximation for many years in the form of Alfven wings. The typical propagation within the characteristic cone has recently been observed during beam operations on the shuttle. Here, the wave power appears sharply confined within the whistler cone at all frequencies between the lower hybrid and the electron gyrofrequency, and results of numerical integration appear to be in reasonable agreement with the observations.

SPACE SYSTEMS ENVIRONMENT INTERACTIONS TECHNOLOGY

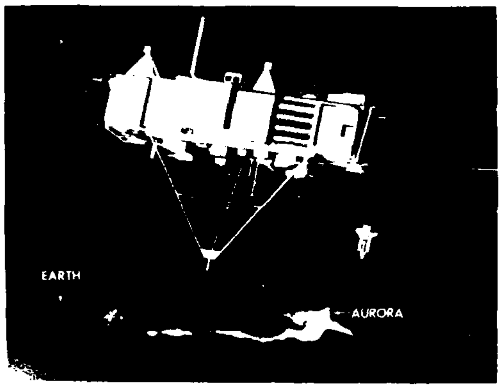
The Space Systems Environment Interactions Technology Program addresses the impact of the space environment on large space structures and systems to be designed and built for use in the 1990's and beyond. The program capitalizes on space environment research results carried out at AFGL and other DoD and civilian research agencies. Its purpose is to transition new knowledge about the environmental sensitivities of emerging technologies into the design and development of future space systems.

A review of Air Force and NASA research program results on the interaction of the space environment with space systems was completed. The review identified seven interaction areas which can be critical to large, high-powered space systems. These are spacecraft charging, radiation, contamination, atomic oxygen erosion, micrometeoroid and man-made debris impacts, high-voltage interactions, and mechanical stresses. The status of existing standards and specifications in these areas was also reviewed. A list of recommended standards, handbooks, computer-aided engineering tools, and prehandbooks was prepared. (Prehandbooks summarize available knowledge in areas which are not sufficiently mature for standards to be prepared.)

Spacecraft charging effects on astronaut extravehicular activity (EVA) equipment were identified as a high-interest topic. AFGL, working with the NASA Johnson Space Center Crew Systems Division and the Air Force Space Division Office of Manned Spaceflight, conducted an initial evaluation of the effects of polar-auroral charging on extravehicular activity (EVA) equipment. The evaluation showed that charging is expected to result when extravehicular activity is conducted during the infrequent severe auroral substorms that can occur at any moment. Arc discharges are expected to result for extreme values of differential charging. Currently, the consequences of charging on the EVA equipment cannot be predicted. Even if the existing electrostatic discharge test were used, it is not considered definitive or predictive of subsequent performance in space. A program to validate electrostatic discharge testing, using the existing EVA equipment as a target system for test development, has been proposed. It would provide the answers for the EVA equipment, as well as validate a test which would benefit all space systems.

The Interactions Measurement Payloads (IMPs) project is planned as a series of integrated payloads to be carried on low-altitude, high-inclination space shuttle flights (see the figure). The IMPs will be instrumented to quantify the adverse effects of space on materials, equipment, and technologies. Typical interaction effects anticipated include atomic oxygen erosion, differential charging, material degradation, and arc-discharge.

The first complement of engineering investigations (experiments) and environmental diagnostics sensors has been de-



Interactions Measurement Payloads (IMPs).

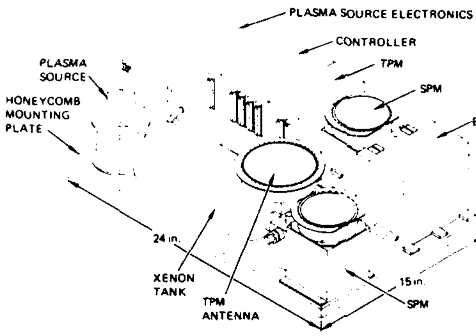
fined. The Photovoltaic Array Space Power (PASP) experiment will measure the space-environment effects on the performance envelopes of selected solar-array technologies (GaAs cells, a conductor-encapsulated array, several types of concentrator arrays) having particular military applications, e.g., enhanced reliability (at higher voltage levels) and lessened vulnerability to laser attack. The Arizona Imager-Spectrograph (AIS) experiment will measure the spatial and temporal characteristics of optical emission (resulting from spacecraft-environment interactions) that could interfere with the operation of military laser and optical surveillance space systems. The Surface Potential Monitor (SPM) experiment will measure surface differential charging and material property changes induced by the space environment on materials typically used in spacecraft construction. A Transient Pulse Monitor (TPM) instrument will detect arc discharges on various IMPs experiments and determine arc-pulse characteristics.

The IMPs environmental diagnostics are being integrated as a group by the AFGL Aerospace Engineering Division. The package will contain a pressure gauge (to measure ambient atmospheric pressure), a quadrupole mass spectrometer (to measure neutral and positive-ion composition), an electrostatic analyzer (to measure the spectral and directional characteristics of energetic electrons and ions), a differential ion-flux probe (to measure enhancements in the vector ion flow), a superthermal electron spectrometer (to measure the low-energy, 0-20 eV, electron spectrum), and a plasmas and fields instrument (to measure ac and dc electric and magnetic fields).

Design of the engineering experiments and environmental sensors began in mid-1985. Preliminary Design Reviews will be completed in January, 1987. The Critical Design Reviews for the experiments and sensors are scheduled to be completed in early 1988. Flight instrument delivery is expected in mid-1989. Flight of the full IMPs on a free-flyer subsatellite deployed from the shuttle is expected in the 1990-92 timeframe. An earlier flight of a lesser IMPs complement is being evaluated for an earlier launch opportunity.

The automated Charge Control System (CCS) is based on results from the Spacecraft Charging at High Altitudes (SCATHA) program. Geosynchronous SCATHA operations demonstrated that satellite surface charge could be actively controlled (dissipated) using a plasma source. The prototype CCS, being developed under contract to Hughes Research Laboratories, will have three charge detection capabilities: (1) an electron and proton electrostatic analyzer, (2) a surface potential monitor, and (3) a transient pulse monitor. A new quick-start neutral plasma source has been designed to essentially clamp the spacecraft to the background plasma and provide a mechanism to dissipate any differen-

CHARGE CONTROL SYSTEM



Perspective View of Automated Charge Control System.

tial charge build-up before a potentially harmful discharge can occur.

The breadboard demonstration showed that the CCS being developed is capable of operating as designed to mitigate charge build-up on geosynchronous spacecraft. The prototype design has been completed and the contractor has begun fabrication of the flight units. NASA/NOAA has proposed flying the prototype unit on a Geostationary Operational Environmental Satellite (GOES) in FY90. Flight units are scheduled for delivery to the Space Test Program in 1988.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

ALTROCK, R.C. (AFGL); MUSMAN, S. (Natl. Oceanic and Atmospheric Admin., Rockville, MD); and COOK, M.C. (Univ. of Leicester, Leicester, England)
The Evolution of an Average Solar Granule
Proc. Conf. on Small-Scale Dynamical Processes in Quiet Stellar Atmospheres (1985)

BAKER, K.B., GREENWALD, R.A. (The Johns Hopkins Univ., Laurel, MD); WALKER, A.D.M. (Univ. of Natal, Durban, South Africa); BYTHROW, P.F., ZANETTI, L.J. (The Johns Hopkins Univ., Laurel, MD); HARDY, D.A., RICH, F.J. (AFGL); and RINO, C.L. (Stanford Research Inst., Menlo Park, CA)
A Case Study of Plasma Processes in the Dayside Cleft
J. Geophys. Res. 91 (1 March 1986)

BORNMANN, P.L.
Turbulence as a Proposed Intermediate Energy Storage Mechanism During Solar Flares in *The Lower Atmosphere of Solar Flares: Proceedings of the Symposium at the National Solar Observatory,*
ed. by D. F. Neidig (1986)

BURKE, W.J. (AFGL); and DOYLE, M.A. (Regis Coll., Weston, MA)
Interplanetary Control of High Latitude Electrodynamics
J. Geomagnetism and Geoelectricity 38 (1986)

BURKE, W.J. (AFGL); VILLALON, E. (Northeastern Univ., Boston, MA); ROTHWELL, P.L. (AFGL); and SILEVITCH, M. (Northeastern Univ., Boston, MA)
Some Consequences of Intense Electromagnetic Wave Injection into Space Plasmas
Proc. Conf. on Space Technology Plasma Issues (1 November 1986)

BYTHROW, P.F. (The Johns Hopkins Univ., Laurel, MD); BURKE, W.J. (AFGL); POTEMRA, T.A., ZANETTI, L.J., and LUI, A.T.Y. (The Johns Hopkins Univ., Laurel, MD)
Ionospheric Evidence for Turbulent Reconnection and Plasma Flows in the Magnetic Tail During Periods of Northward IMF
J. Geophys. Res. 90 (June 1985)

CARINI, P., KALMAN, G., SHIMA, Y. (Boston Coll., Newton, MA); LAI, S.T., and COHEN, H. (AFGL)
Particle Trajectories Between Charged Surfaces
J. Appl. Phys. 19 (1986)

CLIVER, E.W. (AFGL); MCNAMARA, L.F. (Ionospheric Prediction Service, Darlinghurst, New South Wales, Australia); and GENTILE, L.C. (Emmanuel Coll., Boston, MA)
Peak Flux Density Spectra of Large Solar Radio Bursts and Proton Emission from Flares
J. Geophys. Res. 90 (1 July 1985).

CLIVER, E.W. (AFGL); KAHLER, S.W. (Emmanuel Coll., Boston, MA); CANE, H.V., MCGUIRE, R.E., VON ROSENVINGE, T.T. (NASA/Goddard Space Flight Ctr., Greenbelt, MD); and STONE, R.G. (Naval Res. Lab., Washington, DC)
Fast Drift Kilometric Bursts and Solar Proton Events
19th Internat. Cosmic Ray Conf. Papers 4 (1985)

CLIVER, E.W. (AFGL); KAHLER, S.W. (Emmanuel Coll., Boston, MA); SHEELEY, N.R., HOWARD, R.A. (Naval Research Lab., Washington, DC); KOOMEN, M.J. (Sachs-Freeman Assoc., Inc., Bowie, MD); and MICHELS, D.J. (Naval Research Lab., Washington, DC)
Characteristics of Coronal Mass Ejections Associated with Solar Front-Side and Back-Side Metric Type II Bursts
J. Geophys. Res. 90 (January 1985)

CLIVER, E.W. (AFGL); DENNIS, B.R., KIPLINGER, A.L. (NASA Goddard Space Flight Ctr., Greenbelt, MD); KANE, S.R. (Univ. of California, Berkeley, CA); NEIDIG, D.F. (AFGL); SHEELEY, N.R., and KOOMEN, M.J. (Naval Research Lab., Washington, DC)
Solar Gradual Hard X-Ray Bursts and Associated Phenomena
Astrophys. J. 305 (15 June 1986)

COOKE, D.J. (Univ. of Utah, Salt Lake City, UT); HUMBLE, J.E. (Univ. of Tasmania, Hobart, Australia); SHEA, M.A., SMART, D.F. (AFGL); LUND, N., RASMUSSEN, I.L., BYRNAK, B. (Danish Space Research Inst., Lyngby, Denmark); GORET, P., PETROU, N. (Centre d'Etudes Nucl. de Saclay, Saclay, France)
Re-Evaluation of Cosmic Ray Cutoff Terminology
19th Internat. Cosmic Ray Conf. Papers 5 (1985)

DENIG, W.F., and RICH, F.J.
The Ionosphere-Magnetosphere Structure During a Geomagnetic Storm Based on Measurements in the Morning Auroral Zone
J. Geophys. Res. 91 (1 January 1986)

DOBSON-HOCKEY, A.K. (New Mexico St. Univ., University Park, NM); and RADICK, R.R. (AFGL)
On a Technique for Inferring Sizes of Stellar Active Regions in *Cool Stars, Stellar Systems, and the Sun IV*,
ed. by M. Zeilik and D.M. Gibson, pub. by Springer-Verlag (1986)

DOYLE, M.A. (Regis Coll., Weston, MA); BURKE, W.J., HARDY, D.A., (AFGL); BYTHROW, P.F. (The Johns Hopkins Univ., Laurel, MD); RICH, F.J. (AFGL); and POTEMRA, T.A. (Office of Sci. and Tech. Policy, Washington, DC)
A Simple Model of Auroral Electrodynamics Compared with HILAT Measurements
J. Geophys. Res. 91 (1 June 1986)

DRYER, M. (NOAA, Boulder, CO); and SHEA, M.A. (AFGL)
STIP Symposium on Retrospective Analyses and Future Coordinated Intervals
EOS (March-April 1986)

DRYER, M. (NOAA/ERL Boulder, CO); and SMART, D.F. (AFGL)
Dynamical Models of Coronal Transients and Interplanetary Disturbances
Adv. Space Res. 4 (1984)

DRYER, M. (NOAA/ERL, Boulder, CO); WU, S.T. (Univ. of Alabama, Huntsville, AL); GISLASON, G. (Univ. of Alaska, Fairbanks, AK); HAN, S.M. (Tennessee Tech. Univ., Cookeville, TN); SMITH, Z.K. (NOAA/ERL, Boulder, CO); WANG, J.F. (Univ. of Alabama, Huntsville, AL); SMART, D.F., and SHEA, M.A. (AFGL)
Magnetohydrodynamic Modelling of Interplanetary Disturbances Between the Sun and Earth
Astrophys. and Space Sci. 105 (1984)

DULICK, M., and MURAD, E. (AFGL); and BARROW, R.F. (Oxford Univ., Oxford, UK)
Thermochemical Properties of the Rare Earth Monoxides
J. Chem. Phys. 85 (1 July 1986)

DUNN, R.B. (National Solar Observatory, Sunspot, NM) and NOVEMBER, L.J., (AFGL)
Collages of Granulation Pictures
Proc. 8th European Regional Mtg. in Astronomy (1985); in *High Resolution in Solar Physics*, ed. by R. Mullen, pub. by Springer-Verlag (1985)

DUNN, R.B., (National Solar Observatory, Sunspot, NM) and SPENCE, G.E., (AFGL)
Granulation Data Set
Proc. Conf. on Small-Scale Dynamical Processes in Quiet Stellar Atmospheres (1984)

DURNEY, B.R. (Natl. Solar Obs., Sacramento Peak, NM); CRAMM, L.E. (CSIRO, Sydney, Australia); GUENTHER, D.B. (Yale Univ., New Haven, CT); KEIL, S.L. (AFGL); and LYTLE, D.M. (Natl. Solar Obs., Sacramento Peak, NM)
A Search for Long-Lived Velocity Fields at the Solar Poles
Astrophys. J. 292 (15 May 1985)

FARRELL, G.E. (Emmanuel Coll., Boston, MA); FILZ, R.C. (AFGL); HANSER, F.A. (Panametrics, Inc., Waltham, MA); HOLEMAN, E. (Emmanuel Coll., Boston, MA)
Energy Deposition in Silicon Detectors in Earth Orbit
Proc. IEEE 22nd An. Conf. on Nuclear and Space Radiation Effects (22-24 July 1985)

FLÜCKIGER, E.O. (Physikalisches Institut, Universitat Bern, Bern, Switzerland); SMART, D.F., and SHEA, M.A. (AFGL)
A Procedure for Estimating the Changes in Cosmic Ray Cutoff Rigidities and Asymptotic Directions at Low and Middle Latitudes During Periods of Enhanced Geomagnetic Activity
J. Geophys. Res. 91 (1 July 1986)

FLÜCKIGER, E.O. (Physikalisches Institut, Universitat Bern, Bern, Switzerland); SMART, D.F., SHEA, M.A. (AFGL); GENTILE, L.C., and BATHURST, A.A. (Emmanuel Coll., Boston, MA)
Estimating the Change in Asymptotic Direction Due to Secular Changes in the Geomagnetic Field
19th Internat. Cosmic Ray Conf. Papers 5 (1985)

GELPI, C., HUGHES, W.J. (Boston Univ., Boston, MA); and SINGER, H.J. (AFGL)
Longitudinal Phase and Polarization Characteristics in Mid-Latitude Pi 2 Pulsations
J. Geophys. Res. 90 (1 October 1985)

GELPI, C., HUGHES, W.J. (Boston Univ., Boston, MA); SINGER, H.J. (AFGL); and LESTER, M. (Univ. of York, Heslington, UK)
Mid-Latitude Pi 2 Polarization Pattern and Synchronous Orbit Magnetic Activity
J. Geophys. Res. 90 (1 July 1985)

GILLIES, K. (NOAO, Tucson, AZ); AFRICANO, J.L., KLIMKE, A., PARKS, J., ROGERS, W. (Cloudcroft Obs., Cloudcroft, NM); QUIGLEY, R. (Western Washington Univ., Bellingham, WA); EASON, E.L.E. (Aerospace Corp., Los

Angeles, CA); and RADICK, R.R. (AFGL)
Eclipse Timings of RW Trianguli
Pub. Astron. Soc. of Pacific (October, 1986)

GORNEY, D.J. (Aerospace Corp., Los Angeles, CA); EVANS, D.S. (Space Environment Lab., Boulder, CO); GUSSENHOVEN, M.S. (AFGL); and MIZERA, P.F. (Aerospace Corp., Los Angeles, CA)
A Multiple-Satellite Observation of the High-Latitude Auroral Activity on January 11, 1983
J. Geophys. Res. 91 (1 January 1986)

GREEN, B.D. (Physical Sciences, Inc., Andover, MA); and MURAD, E. (AFGL)
The Shuttle Glow as an Indicator of Material Changes in Space
Planetary and Space Sci. 34 (1986)

GUSSENHOVEN, M.S., HARDY, D.A. (AFGL); and CAROVILLANO, R.L. (Boston Coll., Newton, MA)
Average Electron Precipitation in the Polar Cusps, Cleft and Cap in *The Polar Cusp,*
ed. by J.A. Holtet and A. Egland, D. Reidel Pub. Co. (1985)

GUSSENHOVEN, M.S., HARDY, D.A., RICH, F., BURKE, W.J. (AFGL); and YEH, H.-C (Boston Coll., Newton, MA)
High-Level Spacecraft Charging in the Low-Altitude Polar Auroral Environment
J. Geophys. Res. 90 (1 November 1985)

HALL, W.N. (AFGL); LEUNG, P. (JPL, Pasadena, CA); KATZ, I., JONGEWARD, G.A., LILLEY, J.R. (S-Cubed, Inc., La Jolla, CA); NANEVICZ, J.E., THAYER, J.S. (SRI, Inc., Menlo Park, CA); and STEVENS, N.J. (TRW, Inc., Redondo Beach, CA)
Polar-Auroral Charging of the Space Shuttle and EVA Astronaut
Proc. Electromagnetic Wave Propagation Panel Symp. (2-5 June 1986)

HARDY, D.A., GUSSENHOVEN, M.S. (AFGL); and HOLEMAN, E. (Emmanuel Coll., Boston, MA)
A Statistical Model of Auroral Electron Precipitation
J. Geophys. Res. 90 (1 May 1985)

HARDY, D.A., GUSSENHOVEN, M.S., RIEHL, K. (AFGL); BURKHARDT, R., HEINEMANN, N., and SCHUMAKER, T.L. (Boston Coll., Newton, MA)
The Characteristics of Polar Cap Precipitation and Their Dependence on the Interplanetary Magnetic Field and the Solar Wind
Proc. AGU Chapman Conf. on Solar Wind-Magnetospheric Coupling (12-15 February 1985)

HILL, F. (Natl. Solar Obs., Tucson, AZ); HABER, D.A., TOOMRE, J. (Univ. of Colorado, Boulder, CO); and NOVEMBER, L.J. (AFGL)
Influences of Spatial Filtering on Possible Anisotropies in Solar Oscillations in *Seismology of the Sun and the Distant Stars,*
ed. by D.O. Gough, D. Reidel Pub. Co. (1986)

HOLZER, R.E., MCPHERRON, R.L. (Univ. of California, Los Angeles); and HARDY, D.A. (AFGL)
A Quantitative Empirical Model of the Magnetospheric Flux Transfer Process
J. Geophys. Res. 91 (1 March 1986)

HONES, E.W. (Los Alamos National Lab., Los Alamos, NM); ROSENBERG, T.J. (Univ. of Maryland, College Park, MD); and SINGER, H.J. (AFGL)
Observed Associations of Substorm Signatures at South Pole, at the Auroral Zone, and in the Magnetotail
J. Geophys. Res. 91 (1 March 1986)

HUGHES, W.J. (Boston Univ., Boston, MA) and SINGER, H.J. (AFGL)
Mid-Latitude Pi 2 Pulsations, Geosynchronous Substorm Onset Signatures and Auroral Zone Currents on March 22, 1979: CDAW 6
J. Geophys. Res. 90 (1 February 1985)

HUMBLE, J.E. (Univ. of Tasmania, Hobart, Tasmania, Australia); SHEA, M.A., and SMART, D.F. (AFGL)
Sensitivity of Cosmic Ray Trajectory Calculations to Geomagnetic Field Model Representations
Phys. of the Earth and Planetary Interiors 37 (1985)

HUMBLE, J.E. (Univ. of Tasmania, Hobart, Tasmania, Australia); SMART, D.F., and SHEA, M.A. (AFGL)
Empirical Model for the Earth's Cosmic Ray Shadow at 400 KM: Prohibited Cosmic Ray Access
19th Internat. Cosmic Ray Conf. Papers 5 (1985)

KAHLER, S.W. (Emmanuel Coll., Boston, MA); CLIVER, E.W. (AFGL); CANE, H.V., MCGUIRE, R.E., STONE, R.G. (Goddard Space Flight Ctr., Greenbelt, MD); and SHEELEY, N.R. (Naval Research Lab., Washington, DC)
Energetic Protons from a Disappearing Solar Filament
19th Internat. Cosmic Ray Conf. Papers 4 (1985)
Solar Filament Eruption and Energetic Particle Events
Astrophys. J. 302 (March 1986)

KAN, J.R., and BURKE, W.J.
A Theoretical Model of Polar Cap Auroral Arcs
J. Geophys. Res. 90 (1 May 1985)

KANE, S.R., LOVE, J.J. (Univ. of California, Berkeley, CA); NEIDIG, D.F., and CLIVER, E.W. (AFGL)
Characteristics of the White-Light Source in the 1981 April 24 Solar Flare
Astrophys. J. 290 (1 March 1985)

KATZ, I., and RUBIN, A.
Surface Charging
Proc. Shuttle Experiment Environment Wkshp. (13-15 November 1985)

KEIL, S.L.
Position Paper: How Should Observers Prepare for the SOT Hydrodynamic Experiments
Proc. Wkshp. on Theoretical Problems in High Resolution Solar Physics (November 1986)

KEIL, S.L., MARMOLINO, C.
Diagnostics for Propagating Waves in the Solar Photosphere
Astrophys. J. 310 (1986)

KIRKPATRICK, M.E., STEVENS, N.J. (TRW, Inc., Redondo Beach, CA); and HALL, W.N. (AFGL)
Space Station Interactions with the Combined Meteoroid, Debris, and Atomic Oxygen Environments
Proc. AIAA 3rd Space Systems Technology Conf. (9-12 June 1986)

LAI, S.T., COHEN, H.S. (AFGL); AGGSON, T.L. (NASA Goddard Space Flight Ctr., Greenbelt, MD); and MCNEIL, W.J. (RADEX, Inc., Carlisle, MA)
Boom Potential of a Rotating Satellite in Sunlight
J. Geophys. Res. 91 (1 November 1986)

LEBLANC, Y. (Observatoire de Paris, France); SMART, D.F., and SHEA, M.A. (AFGL)
Kilometric Type II Radiation from Interplanetary Shocks: Interpretation of Voyager Results
Adv. in Space Res. 6 (1) (1986)

LITES, B.W. (High Altitude Obs., Boulder, CO); NEIDIG, D.F. (AFGL); TRUJULLO, J. (Kiepenheuer Institut fur Sonnenphysik, Freiburg, FRG)
The Visible Helium Spectrum of a White-Light Flare in *The Lower Atmosphere of Solar Flares: Proceedings of the Symposium at the National Solar Observatory,*
ed. by D. F. Neidig (1986)

MULLEN, E.G., GUSSENHOVEN, M.S., HARDY, D.A. (AFGL); AGGSON, T.A., LEDLEY, B.G. (Goddard Space Flight Ctr., Greenbelt, MD); and WHIPPLE, E. (Univ. of California, San Diego, CA)
SCATHA Survey of High Level Spacecraft Charging in Sunlight
J. Geophys. Res. 91 (1 February 1986)

MURAD, E.
Implications of Mass Spectrometric Measurements on Space Shuttle
Planetary Space Sci. 33 (1985)
Mass Spectrometric Techniques in *Spectrometric Techniques IV*,
ed. by G. Vanasse, Academic Press (1985)

MURAD, E., and LAI, S.T.
The Reaction of N^+ with H_2O by Tandem Mass Spectrometry
Proc. Am. Soc. for Mass Spectrometry Mtg. (26-31 May 1985)
An Experiment to Study the Critical Ionization Velocity Theory in Space
J. Geophys. Res. 91 (1 September 1986)
Some Charge Exchange Reactions Involving H_2O
Chem. Phys. Lett. 126 (16 May 1986)
Effect of Dissociative Electron-Ion Recombination on the Propagation of Critical Ionization Discharges
J. Geophys. Res. 91 (1 December 1986)

MURAD, E., LAI, S.T., and STAIR, A.T., JR.
A Proposed Experiment to Study the Critical Ionization Velocity Theory in Space
J. Geophys. Res. 91 (1 September 1986)

NAKAI, H. (Makino High School, Osaka, Japan); KAMIDE, Y. (Kyoto Sangyo Univ., Kyoto, Japan); HARDY, D.A., and GUSSENHOVEN, M.S. (AFGL)
Time Scales of Expansions and Contraction of the Auroral Oval
J. Geophys. Res. 91 (1 April 1986)
The Dynamics of the Equatorward Boundary of the Auroral Oval in *Solar Wind - Magnetosphere Coupling*,
eds. Y. Kamide and J.A. Slavin, TERRAPUB, Tokyo (1986)

NEIDIG, D.F.
Direct Measurements of the Optical Thickness and Radiative Source Function in the Optical Continuum of Solar Flares; On the Possibility of a Purely Chromospheric Origin for the Bright Kernels in White Light Flares in *The Lower Atmosphere of Solar Flares: Proceedings of the Symposium at the National Solar Observatory*,
ed. D.F. Neidig (1986)

NEIDIG, D.F. (AFGL); KANE, S.R., LOVE, J.J. (Univ. of California, Berkeley, CA); and CLIVER, E.W. (AFGL)
Why P/OF Should Look for Evidences of Over-Dense Structures in Solar Flare Hard X-Ray Sources in *Solar Flares and Coronal Physics Using P/OF as a Research Tool*
ed. E. Tandberg-Hanssen
NASA Conf. Pub. 2421 (1986)

NOVEMBER, L.J.
Measurement of Geometric Distortion in a Turbulent Atmosphere
Appl. Opt. 25 (1 February 1986)

RADICK, R.R. (AFGL); LOCKWOOD, G.W., and THOMPSON, D.T. (Lowell Obs., Flagstaff, AZ)
Variability Characteristics of Lower-Main Sequence Hyades Stars in *Cool Stars, Stellar Systems, and the Sun IV*,
ed. by M. Zeilik and D.M. Gibson, pub. by Springer-Verlag (1986)

RAO, Y.V. (Space Radiation Lab., Lexington, MA); THOMPSON, A. (Dublin Inst. for Advanced Studies, Dublin, Ireland); and FILZ, R.C. (AFGL)
A Study of Low Energy Heavy Cosmic Rays Using CR-39 Track Detector
Proc. 13 Internat. Conf. on Solid State Nuclear Track Detecting (23 September 1985)

REES, D., FULLER-ROWELL, T.J., GORDON, R., SMITH, M.F. (University Coll., London, England); MAYNARD, N.C. (AFGL); HEPPNER, J.P., SPENCER, N.W., WHARTON, L. (Goddard Space Flight Ctr., Greenbelt, MD); HAYS, P.B., and KILLEEN, T.L. (Univ. of Michigan, Ann Arbor, MI)
A Theoretical and Empirical Study of the Response of the High Latitude Thermosphere to the Sense of the "Y" Component of the Interplanetary Magnetic Field
Planetary and Space Sci. 34 (1986)

RIEHL, K.B., and HARDY, D.A.
Average Characteristics of the Polar Rain and Their Relationship to the Solar Wind and the Interplanetary Magnetic Field
J. Geophys. Res. 91 (1 February 1986)

ROBINSON, R.M. (Lockheed Palo Alto Res. Lab., Pasadena, CA); RICH, F. (AFGL); and VONDRAK, R.R. (Lockheed Palo Alto Res. Lab., Pasadena, CA)
Chatanika Radar and S3-2 Measurements of Auroral-Zone Electrodynamics in the Midnight Sector
J. Geophys. Res. 90 (September 1985)

ROTHWELL, P.L.
An Empirical Relationship Between K_p and the Tail Lobe Magnetic Field
J. Geophys. Res. 91 (1 August 1986)

ROTHWELL, P.L. (AFGL); SILEVITCH, M.B. (Northeastern Univ., Boston, MA); and BLOCK, L.P. (Royal Inst. of Tech., Stockholm, Sweden)
Pi 2 Pulsations and the Westward Traveling Surge
J. Geophys. Res. 91 (1 June 1986)

RUBIN, A.G. and BESSE, A.
Charging of a Manned Maneuvering Unit in the Shuttle Wake
J. Spacecraft and Rockets 122 (1986)

RUBIN, A., DENIG, W. (AFGL); and RAITT, W. (Univ. of Utah, Logan, UT)
RAM/WAKE (Database Input)
Proc. Shuttle Experiment Environment Wkshp. (1985)

SAFLEKOS, N.A. (Boston Coll., Newton, MA); BURKE, W.J., and FOUGERE, P.F. (AFGL)
Large-Amplitude Electric Field Fluctuations Near the Harang Discontinuity
Radio Sci. 20 (May-June 1985)

SANDHOLT, P.E., EGELAND, A., ASHEIM, S., LYBEKK, B. (Univ. of Oslo, Oslo, Norway); and HARDY, D.A. (AFGL)
The Polar Cusp: Optical and Particle Characteristics-Dynamics
Memoirs of Natl. Inst. of Polar Res., Special Issue 38 (December 1985)

SCHMIDT, H.U. (Max Planck Institut fur Physik, Federal Republic of Germany); SIMON, G.W. (AFGL); and WEISS, N.O. (Univ. of Cambridge, Cambridge, UK)
Buoyant Magnetic Flux Tubes. II. Three-Dimensional Behavior in Granules and Supergranules
Astron. Astrophys. 148 (1985)

SHEA, M.A.
Cosmic Rays and Heavy Ion Environments
Proc. of Spacecraft Anomalies Conf. (1984)

SHEA, M.A. (AFGL); and ALLEN, J.H. (NOAA/NESDIS, Boulder, CO)
Decline in Global Geomagnetic Observations from 1976-1984
IAGA News 24 (1985)

SHEA, M.A., and SMART, D.F.
An Update on the Correlation Between the Cosmic Radiation Intensity and the Geomagnetic AA Index
19th Internat. Cosmic Ray Conf. Papers 4 (1985)
Concepts of Relativistic Solar Particle Events
Proc. Kunming Wkshp. on Solar Phys. and Interplanetary Traveling Phenomena 2 (1985)
Energetic Particle Radiation Environment for Manned Space Operations
Proc. Solar Terrestrial Predictions Wkshp. (1986)
Relativistic Solar Particle Events During the SMY-SMA in *VNU Science Press*
ed. by Stepanov and Obridko, Science Press (1986)

SHEA, M.A., SMART, D.F. (AFGL); and GENTILE, L.C. (Emmanuel Coll., Boston, MA)
The Use of the McIlwain L-Parameter to Estimate Cosmic Ray Vertical Cutoff Rigidities for Different Epochs of the Geomagnetic Field
19 Internat. Cosmic Ray Conf. Papers 4 (1985)

SHEA, M.A., SMART, D.F. (AFGL); SWINSON, D.B. (Univ. of New Mexico, Albuquerque, NM); and HUMBLE, J.E. (Univ. of Tasmania, Hobart, Tasmania, Australia)
North South Asymmetry in Solar Activity and Its Effects on the High Energy Cosmic Ray Diurnal Variation in *The Sun and the Heliosphere in Three Dimensions*,
ed. by R.G. Marsden, pub. by D. Reidel (1986)

SHEA, M.A., SMART, D.F. (AFGL); WADA, M., and INOUE, A. (Institute of Phys. and Chem. Research, Tokyo, Japan)
A Suggested Standardization Format for Cosmic Ray Ground-Level Event Data
19th Internat. Cosmic Ray Conf. Papers 5 (1985)

SIME, D.G., FISHER, R.R. (High Altitude Observatory, Boulder, CO) and ALTROCK, R.C. (AFGL)
Solar Coronal White Light, Fe X, Fe XIV, and Ca XV Observations During 1984. An Atlas of Synoptic Charts
Natl. Ctr. for Atmospheric Res. TN-251-STR (March 1985)

SIMON, G.W. (AFGL); and WILSON, P.R. (Natl. Solar Obs., Sunspot, NM)
Flux Changes in Small Magnetic Regions. II. Further Observations and Analysis
Astrophys. J. 295 (1 August 1985)

SIMONS, S.L., REIFF, P.H., SPIRO, R.W. (Rice Univ., Houston, TX); HARDY, D.A. (AFGL); and KROEHL, H.W. (NOAA, Boulder, CO)
A Comparison of Precipitating Electron Energy Flux on March 22, 1979 with an Empirical Model: CDAW 6
J. Geophys. Res. 90 (1 March 1985)

SINGER, H.J. (AFGL); HUGHES, W.J., GELPI, C. (Boston Univ., Boston, MA); and LEDLEY, B.G. (Goddard Space Flight Ctr., Greenbelt, MD)
Magnetic Disturbances in the Vicinity of Synchronous Orbit and the Substorm Current Wedge: A Case Study
J. Geophys. Res. 90 (1 October 1985)

SMART, D.F., and SHEA, M.A.
A Simplified Model for Timing the Arrival of Solar Flare-Initiated Shocks
J. Geophys. Res. 90 (1 January 1985)
Solar-Flare-Initiated Shock Waves; Blast Waves Riding on the Solar Wind
Proc. Kunming Wkshp. on Solar Phys. and Interplanetary Travelling Phenomena 2 (1985)
Application of the "Blast Waves in the Solar Wind" Concept to Major Interplanetary Shocks during the Solar Maximum in *VNU Science Press*
ed. by Stepanov and Obridko, Science Press (1986)

SOJKA, J.J., RAITT, W.J., SCHUNK, R.W., PARISH, J.L. (Utah St. Univ., Logan, UT); RICH, F.J. (AFGL)
Diurnal Variation of the Dayside, Ionospheric, Mid-Latitude Trough in the Southern Hemisphere at 800 KM: Model and Measurement Comparisons
Planetary and Space Sci. 33 (1985)

SWINSON, D.B. (Univ. of New Mexico, Albuquerque, NM); SHEA, M.A. (AFGL); and HUMBLE, J.E. (Univ. of Tasmania, Hobart, Australia)
North-South Asymmetry in Activity on the Sun and Cosmic Ray Density Gradients
19 Internat. Cosmic Ray Conf. Papers 4 (1985)
Cosmic Ray Density Gradients Related to North-South Asymmetry in Activity on the Sun
J. Geophys. Res. 91 (1 March 1986)

VON ZAHN, U. (Physikalisches Institut, Universitat Bonn, Bonn, FRG); and MURAD, E. (AFGL)
NO_2 Emitted from Space Shuttle Surfaces and Shuttle Glow
Nature 321 (8 May 1986)

WEIMER, D.R., GOERTZ, C.K., GURNETT, D.A. (Univ. of Iowa, Iowa City, IA); MAYNARD, N.C. (AFGL); and BURCH, J.L. (Southwest Res. Inst., San Antonio, TX)
Auroral Zone Electric Fields from DE 1 and 2 at Magnetic Conjunctions
J. Geophys. Res. 90 (1 August 1985)

WITT, E.F. (AFGL); and HUDSON, M. (Dartmouth Coll., Hanover, NH)
Electrostatic Shocks as Nonlinear Ion Acoustic Waves
J. Geophys. Res. 91 (March 1986)

YATES, G.K., and HEINEMANN, M.
Three Dimensional Axisymmetric Magnetosphere in Pressure Balance with the Solar Wind
J. Geophys. Res. 91 (1 June 1986)

PRESENTATIONS
JANUARY, 1985 - DECEMBER, 1986

ALTROCK, R.C.
Coronal-Hole Detectability on Solar-Type Stars
165th Mtg. of Am. Astron. Soc., Tucson, AZ (14-16 January 1985)
Coronal Response to Flares
NSO/SMM Summer Workshop, Sunspot, NM (20-24 August 1985)
The Solar-Cycle 21 Variation of High-Latitude Coronal Fe XIV Emission
168th Mtg. of Am. Astron. Soc., Ames, IA (22-26 June 1986)
Solar-Cycle Variation in High-Latitude Coronal FE XIV Emission
The International Solar Cycle Workshop, I: Solar Minimum Phase; Big Bear Solar Observatory, CA (17-20 August 1986)
Coronal Green-Line Transient Statistics,
International Meeting on Solar Events and Their Influence on the Interplanetary Medium, Estes Park, CO (8-11 September 1986)

ALTROCK, R.C. (AFGL); SMITH, R.C. (National Solar Observatory, Sunspot, NM)
The Relationship of Emission-Line Transients in the Low Solar Corona to H-Alpha Activity
AGU Mtg., San Francisco, CA (9-13 December 1985)
The Relationship of Emission-Line Transients in the Low Solar Corona to H-Alpha Activity
Am. Astron. Soc. Mtg. No 167, Houston, TX (6-9 January 1986)

ALTROCK, R.C. (AFGL); FISHER, R.R., and SIME, D.G. (High Altitude Obs., Boulder, CO)
Results from the Coronal Photometry at NSO. I: Three-Line Observations of the Corona in 1984
Am. Astronomical Soc. Mtg., Tucson, AZ (13-15 May 1985)

BASS, J.N. (RADEX, Corp., Carlisle, MA); GUSSENHOVEN, M.S., and REDUS, R.H. (AFGL)
The Importance of Adiabatic Variations in Trapped Particle Distributions Observed by the SCATHA Satellite
AGU Mtg., Baltimore, MD (19-23 May 1986); European Geophys. Soc. Mtg., Kiel, Germany (20-30 August 1986)

BLOCK, L.P. (The Royal Inst. of Tech., Stockholm, Sweden); ROTHWELL, P.L. (AFGL); and SILEVITCH, M.B. (Northeastern Univ., Boston, MA)
A New Model for Substorm Breakup
AGU Mtg., San Francisco, CA (8-12 December 1986)

BURKE, W.J.
Ionospheric Signatures of the Low Latitude Boundary Layer
IAGA 5th Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985)

BURKE, W.J., and DOYLE, M.A.
Interplanetary Control of High Latitude Electrodynamics
IAGA Mtg., Prague, Czechoslovakia (6 August 1985)

BYTHROW, P.F. (JHU/APL, Laurel, MD); DOYLE, M.A. (AFGL); MENG, C.-I. (JHU/APL, Laurel, MD); HUFFMAN, R.E., HARDY, D.A., RICH, F.J. (AFGL); POTEMRA, T.A., and ZANETTI, L.J. (JHU/APL, Laurel, MD)
The Kelvin Helmholtz Instability at the BPS/CPS Interface: A Source of Small-Scale Birkeland Currents and Auroral Arcs
AGU Mtg., Baltimore, MD (27-31 May 1985)

CLIVER, E.W. (AFGL); and KAHLER, S.W. (Emmanuel Coll., Boston, MA)
Scientific Results from STIP Interval XIV - 20 May-20 July 1982
STIP Symp. on Retrospective Analyses and Future Coordinated Intervals, Les Diablerets, Switzerland (10-12 June 1985)

CLIVER, E.W. (AFGL); FORREST, D.J. (Univ. of New Hampshire, Durham, NH); MCGUIRE, R.E., and VON ROSENVINGE, T.T. (NASA/GSFC, Greenbelt, MD)
Solar-Flare Gamma-Rays and Interplanetary Proton Events
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

CLIVER, E.W. (AFGL); MIHALOV, J.D. (NASA Ames Research Ctr., Moffett Field, CA); SHEELEY, N.R., JR., HOWARD, R.A., and KOOMEN, M.J. (NRL, Washington, DC)
Azimuthally-Symmetric Cosmic Ray Modulation and Solar Activity in Mid-1982
AGU Mtg., Baltimore, MD (19-23 May 1986)

CLIVER, E.W. (AFGL); DENNIS, B.R., KIPLINGER, A.L. (NASA Goddard Space Flight Ctr., Greenbelt, MD); KANE, S.R. (Univ. of California, Berkeley, CA); NEIDIG, D.F. (AFGL); SHEELEY, N.R., JR., and KOOMEN, M.J. (NRL, Washington, DC)
Solar Gradual Hard X-Ray Bursts and Associated Phenomena
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

COHEN, H.A., LAI, S.T. (AFGL); and MCNEIL, W.J. (RADEX, Carlisle, MA)
Electron Beam Luminosity on the SCEX Rocket
AGU Mtg., Baltimore, MD (June 1985)
Vehicle Potential Caused by Ejected Electron Current: Non-Monotonic Behavior
AGU Mtg., San Francisco, CA (5-10 December 1985)

COOKE, D. (RADEX Corp., Carlisle, MA); DUBS, C., and HEINEMANN, M. (AFGL)
Cross-Field Transport of Electrons: Implications for the POLAR Code, Spacecraft Charging
AGU Mtg., Baltimore, MD (19-23 May 1986)

COOKE, D.L., TAUTZ, M. (RADEX Corp., Carlisle, MA); and RUBIN, A.G. (AFGL)
The Sheath Edge of a Charged Object in a Flowing Plasma
AGU Meeting, San Francisco, CA (8-12 December 1986)

DENIG, W.F., PIKE, C.P. (AFGL); MENDE, S.B. (Lockheed, Palo Alto, CA); and LEESTMA, D. (NASA-JSC/Houston, TX)
Shuttle Auroral Photography Experiment
AGU Mtg., Baltimore, MD (27-31 May 1985)

DENIG, W.F. (AFGL); BARRETT, J.L., TROWBRIDGE, C. (Photometrics, Inc., Woburn, MA); KENDALL, D.J.W. (Natl. Research Council, Ottawa, Ontario, Canada); and MENDE, S.B. (Lockheed Palo Alto Research Lab., Palo Alto, CA)
Spectrometric Observations of Aurora from Space
AGU Mtg., San Francisco, CA (8-12 December 1986)

DENIG, W.F., PIKE, C.P. (AFGL); MENDE, S.B., SWENSON, G.R. (Lockheed Missiles and Rocket Co., Inc., Palo Alto, CA); KENDALL, D. (NRC, Canada); and LLEWELLYN, E.J. (Univ. of Saskatchewan, Saskatoon, Canada)
Auroral Observation from the Space Shuttle
Internat. Assbly. of Geodesy and Aeronomy, Prague, Czechoslovakia (9-12 August 1985)

DONATELLI, D.E.
Induced Perturbations in Space Plasmas
Internat. Symp. on Space Phys., Beijing, China (10-14 November 1986)

DRYER, M. (NOAA, Boulder, CO); and SHEA, M.A. (AFGL)
Scientific Highlights of the Study of Travelling Interplanetary Phenomena (STIP) Intervals During the SMY/SMA
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

DUBS, C., and HEINEMANN, M.
Ion Trajectories and Current to a Long Conducting Cylinder Moving Thru a Magnetoplasma
AGU Mtg., Baltimore, MD (27-31 May 1985)

ERNSTMEYER, J.
On the Propagation of Instabilities out of a Spatially Confined Electron Beam
AGU Mtg., San Francisco, CA (9-13 December 1985)
Collisionless Heating of Ionospheric Plasma by an Electron Beam
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

FILZ, R.C.
Observations of E>20 meV Solar Protons Over the Polar Caps in April 1984 Using the Dosimeter on the DMSP/F7 Satellite
AGU Mtg., San Francisco, CA (9-13 December 1985)
Trapped Inner Zone Proton Fluxes in 1984-5 Measured with the AFGL DMSP/F7 Dosimeter
AGU Mtg., San Francisco, CA (8-12 December 1986)

FISHER, R.R. (High Altitude Obs., Boulder, CO); ALTROCK, R.C. (AFGL); and SIME, D.G. (High Altitude Obs., Boulder, CO)
Results from the Coronal Photometry Program at NSO, III: The Green Line and White Light Corona Compared
AAS Solar Phys. Div. Conf., Tucson, AZ (13-15 May 1985)

FLÜCKIGER, E.O. (Physikalisches Institut, Universitat Bern, Bern, Switzerland); SMART, D.F., SHEA, M.A. (AFGL); and GENTILE, L.C. (Emmanuel Coll., Boston, MA)
On the Correlation Between Asymptotic Directions of Cosmic Ray Particles and Cutoff Rigidities in the Evolving Geomagnetic Field
AGU Mtg., San Francisco, CA (8-12 December 1986)

FLÜCKIGER, E.O., SCUNTARO, W. (Physikalisches Institut, Universitat Bern, Bern, Switzerland); Smart, D.F., and Shea, M.A. (AFGL)
Determining the Strength of the Ring and the Magnetopause Currents During the Initial Phase of a Geomagnetic Storm Using Cosmic Ray Data
AGU Mtg., San Francisco, CA (8-12 December 1986)

GELPI, C., HUGHES, W.J. (Boston Univ., Boston, MA); and SINGER, H.J. (AFGL)
Longitudinal Phase and Polarization Characteristics of Mid-Latitude Pi 2 Pulsations
IAGA 5th Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985)

GELPI, C. (Boston Univ., Boston, MA); SINGER, H.J. (AFGL); and HUGHES, W.J. (Boston Univ., Boston, MA)
Auroral Surge Forms and Mid-Latitude Magnetic Substorm Signatures
IAGA 5th Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985)

GREEN, B.D. (Physical Sciences, Inc., Andover, MA); and MURAD, E. (AFGL)
The Nature of the Glow and Its Ramifications on Space-Based Observations
AIAA 20th Thermophysics Conf., Williamsburg, VA (19-20 June 1985)

GUIDICE, D.E.
IMPS Investigations of Space-Environment Effects on Enabling Technologies
AIAA 24th Aerospace Mtg., Reno, NV (6-9 January 1986)

GUSSENHOVEN, M.S., and HARDY, D.A.
Parametric Variations in the Polar Rain and the Solar Wind
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

GUSSENHOVEN, M.S., HARDY, D.A. (AFGL); and BRAUTIGAM, D. (Emmanuel Coll., Boston, MA)
Winter-Summer Cusp Asymmetries
AGU Mtg., San Francisco, CA (8-12 December 1986)

GUSSENHOVEN, M.S. (AFGL); CRAVEN, J.D., FRANK, L.A. (Univ. of Iowa, Iowa City, IA); and BAKER, D.N. (Los Alamos Natl. Lab., Los Alamos, NM)
Highly Asymmetric Response of the High Latitude Magnetosphere for Bz Northward
AGU Mtg., San Francisco, CA (9-13 December 1985)

GUSSENHOVEN, M.S., HARDY, D.A., REDUS, R.H. (AFGL); YEH, H.-C. (Boston Coll., Newton, MA); and HEINEMANN, N. (Emmanuel Coll., Boston, MA)
Precipitating Electron and Ion Morphology in the Polar Cap on 11 January 1983
AGU Mtg., Baltimore, MD (19-23 May 1986)

HALL, W.N. (AFGL); JONGEWARD, G.A., KATZ, I., and LILLEY, J.R. (S-Cubed, Inc., LaJolla, CA)
Shuttle and Astronaut Charging in Polar Orbit
AIAA 24th Aerospace Sci. Mtg., Reno, NV (6-8 January 1986)

HALL, W.N. (AFGL); LEUNG, P. (Jet Propulsion Lab., Pasadena, CA); KATZ, I., JONGEWARD, G.A., LILLEY, J.R. (S-Cubed, Inc., La Jolla, CA); NANEVICZ, J.E., THAYER, J.S. (SRI, Internat., Menlo Park, CA); and STEVENS, N.J. (TRW, Inc., Redondo Beach, CA)
Polar-Auroral Charging of the Space Shuttle and EVA Astronaut
Electromagnetic Wave Propagation Panel Symp. (AGARD) The Hague, Netherlands (2-5 June 1986)

HARDY, D.A.
Mass Transfer from the Magnetosphere to the Ionosphere
AGU Mtg., San Francisco, CA (8-13 December 1985)

HARDY, D.A., and BURKE, W.J.
Impulsive Precipitation of Electrons in the Morning Side Diffuse Aurora
AGU Mtg., San Francisco, CA (8-13 December 1985)

HARDY, D.A., GUSSENHOVEN, M.S. (AFGL); and BRAUTIGAM, D. (Emmanuel Coll., Boston, MA)
The Average Global Pattern of Auroral Ion Precipitation
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

HARDY, D.A., GUSSENHOVEN, M.S. (AFGL); HOLEMAN, E., BURKHARDT, R. (Emmanuel Coll., Boston, MA); and HEINEMANN, N. (Boston Coll., Newton, MA)
Variation in the Pattern of High Latitude Particle Precipitation with the Orientation of the IMF
AGU Chapman Conf. on Solar Wind Magnetospheric Coupling, Pasadena, CA (12-15 February 1985)

HEELIS, R.A. (Univ. of Texas, Richardson, TX); WINNINGHAM, J.D. (Southwest Research Inst., San Antonio, TX); MAYNARD, N.C. (AFGL); and BRACE, L.H. (Goddard Space Flight Ctr., Greenbelt, MD)
Magnetospheric Fields in the Mid-Latitude Ionosphere Observed by DE-2
AGU Mtg., Baltimore, MD (19-23 May 1986)

HEINEMANN, M.
A Simulation of Convection and Radial Diffusion in the Inner Magnetosphere
Internat. School for Space Simulations, Kapaa, HI (7-16 February 1985)
Lifetime of Spacecraft Generated Ion Clouds
AGU Mtg., San Francisco, CA (8-12 December 1986)

HEINEMANN, M., and BURKE, W.J.
Signatures of Kinetic Alfven Waves in Electrostatic Shock Observation
AGU Mtg., San Francisco, CA (9-13 December 1985)

HEINEMANN, M., and DONATELLI, D.
The Plasma Wave Field of Spacecraft
AGU Mtg., Baltimore, MD (19-23 May 1986)

HEINEMANN, M. and MURAD, E.
The Path and Collisional Behavior of Shuttle Exhaust During Orbit
Shuttle Environment and Operations II Conf., Houston, TX (13-15 November 1985)

HEINEMANN, M., RUBIN, A. (AFGL); TAUTZ, M., and COOKE, D. (RADEX Corp., Carlisle, MA)
POLAR Code Charging Model: Computer Models of the Spacecraft Wake
NATO-AGARD Conf., The Hague, Netherlands (2-7 June 1986)

HEINEMANN, M. (AFGL); JONGEWARD, G., KATZ, I. (S-Cubed, Inc., La Jolla, CA); RUBIN, A. (AFGL); TAUTZ, M. (RADEX Corp., Carlisle, MA); and DUBS, C. (AFGL)
Magnetic Effects on Spacecraft Charging
AIAA Aerospace Sciences Mtg., Reno, NV (6 January 1985)

HEINEMANN, N. (Emmanuel Coll., Boston, MA); GUSSENHOVEN, M.S., HARDY, D.A., REDUS, R.H. (AFGL); and YEH, H.-C (Boston Coll., Newton, MA)
Auroral Particle Precipitation During a 24 Hour Change from Strong IMF Bz Southward to Strong IMF Bz Northward
AGU Mtg., Baltimore, MD (19-23 May 1986)

HEINEMANN, N. (Boston Coll., Newton, MA); GUSSENHOVEN, M.S., RICH, F.J., HARDY, D.A. (AFGL); and DE LA BEAUJARDIERE, O. (SRI International, Menlo Park, CA)
Comparison of Particle Precipitation, Current and Ionospheric Convection Patterns During a Small, Isolated Substorm
AGU Mtg., San Francisco, CA (9-13 December 1985)

JONSON, E., LT. COL., and HALL, W.N.
Space System Environmental Entanglements - Non-Benign Space Environmental Interactions
Environmental Interactions Tech. Seminar, Redondo Beach, CA (1 July 1986)

KAHLER, S.W. (Emmanuel Coll., Boston, MA); CLIVER, E.W. (AFGL); and CANE, H.V. (NASA/GSFC, Greenbelt, MD)
The Relationship of Shock-Associated Kilometric Radio Emission with Metric Type II Bursts and Energetic Particles
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

KAHLER, S.W. (Emmanuel Coll., Boston, MA); CLIVER, E.W. (AFGL); CANE, H.V., MCGUIRE, R.E., STONE, R.G. (Goddard Space Flight Ctr., Greenbelt, MD); and SHEELEY, N.R. (Naval Research Lab., Washington, DC)
Solar Filament Eruption and Energetic Particle Events
AGU Mtg., Baltimore, MD (27-31 May 1985); 19th Internat. Cosmic Ray Conf., San Diego, CA (11-23 August 1985)

KANE, S.R., LOVE, J.J. (Univ. of California, Berkeley, CA); NEIDIG, D.F., and CLIVER, E.W. (AFGL)
Non-Thermal Excitation of the White Light Source in the 24 April 1981 ~ 1358 UT Solar Flare
AAS Solar Physics Div. Mtg., Tucson, AZ (13-15 May 1985)

KATZ, I., MANDELL, M.J., JONGEWARD, G.A., LILLEY, J.R. (S-Cubed, Inc., La Jolla, CA); HALL, W.N., and RUBIN, A.G. (AFGL)
Astronaut Charging in the Wake of a Polar Orbiting Shuttle
Shuttle Environment and Operations II Conf., Houston, TX (13-15 November 1985)

KEIL, S.L.
Effects of Magnetic Fields on the Asymmetry of Photospheric Line Profiles
AAS Solar Phys. Div. An. Mtg., Tucson, AZ (13-15 May 1985)

KEIL, S.L. (AFGL); and KOO, B.-C. (Univ. of California, Berkeley, CA)
Some Effects of Propagating Wave Packets on Solar Spectral Lines
168th Mtg. of Am. Astron. Soc., Ames, IA (22-26 June 1986)

KEIL, S.L., and NEIDIG, D.F.
Solar Activity Measurement Experiment (SAMEX)
24th Aerospace Sciences Mtg., Reno, NV (6-9 January 1986)

KENDALL, D.J.W., GATTINGER, R.L. (NRC, Ottawa, Canada); LLEWELLYN, E.J. (Univ. of Saskatchewan, Saskatoon, Canada); MENDE, S.B. (Lockheed, Palo Alto, CA); and DENIG, W.F. (AFGL)
Orbiter Glow Observations During Mission STS 41-G
AGU Mtg., San Francisco, CA (9-13 December 1985)

KENDALL, D.J.W. (NRC, Ottawa, Canada); LLEWELLYN, E. (Univ. of Saskatchewan, Saskatoon, Canada); GATTINGER, R. (NRC, Ottawa, Canada); MENDE, S. (Lockheed, Palo Alto, CA); COGGER, L. (Univ. of Calgary, Alberta, Canada); and DENIG, W.F. (AFGL)
Shuttle Glow and Spectrographic Observations from Mission STS 41-G
CAP Cong., Edmonton, Canada (23-25 June 1986)

KIRKPATRICK, M.E., STEVENS, N.J., UNDERWOOD, C.S., HOWARD, J.E. (TRW, Redondo Beach, CA); and HALL, W.N. (AFGL)
Large Space Systems-Natural Environment Interactions in Polar Orbit
AIAA 24th Aerospace Sciences Conf., Reno, NV (6-8 January 1986)

KNECHT, D.J.
Width and Location of Field-Aligned Current Couples Producing the Bay and Pulsations at Substorm Onset
AGU Mtg., San Francisco, CA (9-13 December 1985)

LAI, S.T., and MURAD, E.
Quenching of Critical Ionization in the Vicinity of Space Shuttle
AGU Mtg., Baltimore, MD (19-23 May 1986)

LAI, S.T., COHEN, H.A. (AFGL); and AGGSON, T.L. (Goddard Space Flight Ctr., Green-belt, MD)
Modulation of Boom-Satellite Potential Difference During Ion Beam Ejections in Sunlight
AGU Mtg., Baltimore, MD (27-31 May 1985)

LAI, S.T., COHEN, H.A. (AFGL); and McNEIL, W.J. (RADEX Corp., Carlisle, MA)
Spacecraft Sheath Modification During Beam Ejections
Internat. School for Space Simulations, Honolulu, HI (3-16 February 1985)

LAI, S.T., DENIG, W.F., and MURAD, E.
The Role of the Critical Ionization Velocity Mechanism on Plasma Processes in the Space Shuttle Environment
AGU Mtg., San Francisco, CA (1-12 December 1986)

LAI, S.T., ROTHWELL, P., HEINEMANN, M., and MURAD, E.
Critical Ionization and Polarization Drift of a Dense Neutral Beam in the Ionosphere
AGU Mtg., San Francisco, CA (5-10 December 1985)

LEBLANC, Y. (Observatoire de Paris, France); and SMART, D.F. (AFGL)
Interplanetary Shockwaves Observed by the Voyager Radio Astronomy Experiment During April 1978
STIP Symp. on Restrospective Analyses and Future Coordinated Intervals, Les Diablerets, Switzerland (10-12 June 1985)

LEBLANC, Y. (Observatoire de Paris, France); SMART, D.F., and SHEA, M.A. (AFGL)
Kilometric Type II Radiation from Interplanetary Shocks: Interpretation of Voyager Results
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

LESTER, M. (Univ. of York, UK); and SINGER, H.J. (AFGL)
Pi 2 Pulsations and the Substorm Current Wedge - Polarization Characteristics at Low Latitudes ($L \leq 3$)
IAGA 5th Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985)

LUDLOW, G.R., GELPI, C., HUGHES, W.J. (Boston Univ., Boston, MA); and SINGER, H.J. (AFGL)
Ground-based Observations of a Long Duration Pc 1 Event
AGU Mtg., San Francisco, CA (8-12 December 1986)

LYNCH, K.A., GUSSENHOVEN, M.S., FILZ, R., FOUGERE, P. (AFGL); and BAKER, D.N. (Los Alamos Natl. Lab., Los Alamos, NM)
Power Spectral Density Analysis of Relativistic Outer Zone Electrons at $L = 3$-4
AGU Mtg., San Francisco, CA (9-13 December 1985)

LYNCH, K.A., GUSSENHOVEN, M.S., FILZ, R., MULLEN, E.G. (AFGL); RIECO, S. (AFWL, Kirtland AFB, NM); and HANSER, F.A. (Panametrics, Inc., Waltham, MA)
Comparison of the Measured Dose and the AFWL Satellite Vulnerability Code Calculated Dose for the DMSP/F7 J Dosimeter*
AGU Mtg., Baltimore, MD (19-23 May 1986)

MARMOLINO, C.
The Effects of Acoustic Waves on the Curve of Growth
168th Mtg. of Am. Astron. Soc., Ames, IA (22-26 June 1986)

MAYNARD, N.C. (AFGL); AGGSON, T.L. (Goddard Space Flight Ctr., Greenbelt, MD); LIEBRECHT, C. (Science Applications Research, Lanham, MD); MAYR, H.G., and HERRERO, F.A. (Goddard Space Flight Ctr., Greenbelt, MD)
Observations of Low Latitude Meridional Electric Fields from DE-2
AGU Mtg., Baltimore, MD (19-23 May 1986)

MAYNARD, N.C., BABCOCK, R.R., GUIDICE, D.A., PIKE, C.P. (AFGL); and GARRETT, H.B. (JPL, Pasadena, CA)
A Program for Measuring Large-Body Space-Plasma Interactions in the Auroral and Polar Cap Environments
Shuttle Environment and Operations II Conf., Houston, TX (13-15 November 1985)

MENDE, S.B., SWENSON, G.R. (Lockheed Research Lab., Palo Alto, CA); KENDALL, D.J.W., (NRC, Ontario, Canada); LLEWELLYN, E.J. (Univ. of Saskatchewan, Saskatoon, Canada); and DENIG, W.F. (AFGL)
Image Intensified Spectrograph Observations on the STS 41-G Mission
AGU Mtg., Baltimore, MD (27-31 May 1985)

MULLEN, E.G.
A Space Radiation Effects Program (SPACERAD)
3rd An. Symp. on Single Event Effects, Los Angeles, CA (5-6 March 1985); 4th An. Symp. on Single Event Effects, Los Angeles, CA (8-9 April 1986)

MULLEN, E.G., and GUSSENHOVEN, M.S.
Spin Variations in Spacecraft Charging
AGU Mtg., San Francisco, CA (9-13 December 1985)
DMSP Dosimeter Data for the 1986 February Storm
AGU Mtg., San Francisco, CA (8-12 December 1986)

MULLEN, E.G., GUSSENHOVEN, M.S., LYNCH, K.A., and BRAUTIGAM, D.
Nuclear Star Events in Slab Detectors: An In-Situ Measurement of SEU Phenomena
Internat. Federation of Automatic Control Wkshp., Paris, France (15-17 December 1986)

MURAD, E.
Glow of Spacecraft in Low Earth Orbit
Sixth An. MIT Symp. on Phys. of Space Plasma. Cambridge, MA (10 January 1986)
The Role of Atomic and Molecular Processes in the Critical Ionization Velocity Theory
Internat. Symp. for Sir David Bates, Belfast, No. Ireland (17-18 November 1986)

MURAD, E., and LAI, S.T.
The Reaction of O+ with H_2O
10th Internat. Mass Spectrometry Conf., Swansea, UK (9-13 September 1985)

MURAD, E., LAI, S.T., and STAIR, A.T., JR.
Critical Ionization Velocity and Its Implications for Space Plume Modelling - A Proposed Test in Space
AIAA 24th Aerospace Sciences Mtg., Reno, NV (6-9 January 1986)

NEIDIG, D.F.
AFGL Planned Efforts in Solar Monitoring from Space
Solar High-Resolution Astrophysics Using the Pinhole Occulter Facility Wkshp. Marshall Space Flight Ctr., AL (8-10 May 1985)

NEIDIG, D.F.; KANE, S.R.; LOVE, J.J.; CLIVER, E.W.
Non-Thermal Excitation of the White Light Source in the 24 April (1358 UT) Solar Flare
Am. Astron. Soc. Solar Phys. Div. Mtg., Tucson, AZ (13-15 May 1985)

NOVEMBER, L.J. (AFGL); and DUNN, R.B. (National Solar Obs., Sunspot, NM)
Atmospheric Distortion and Blurring
AAS Solar Phys. Div. Mtg., Tucson, AZ (13-15 May 1985)

NOVEMBER, L.J. (Natl. Solar Obs., Sac Peak, NM); SIMON, G.W. (AFGL);

TARBELL, T., and TITLE, A. (Lockheed Research Lab., Palo Alto, CA)
Precise Proper Motion Measurement of Solar Granulation
168th Mtg. of Am. Astron. Soc., Ames, IA (22-26 June 1986)

PIKE, C.P.
Space Systems and Their Interactions with the Space Environment
Naval Postgraduate School (24 April 1986)

PIKE, C.P. (AFGL); PURVIS, C.K. (NASA Lewis Res. Ctr., Cleveland, OH); KATZ, I. (S-Cubed, La Jolla, CA); and RUBIN, A.G. (AFGL)
Spacecraft Charging Computer Modeling
Military Operations Res. Soc. Mtg., Colorado Springs, CO (25-27 June 1985)

RADICK, R.R.
The Solar-Stellar Connection at Low Spectral Resolution
Proceedings of the NSO Workshop on Solar-Stellar Initiatives, Tucson, AZ (3-5 September 1986)

RADICK, R.R. (AFGL); DUNCAN, D.K. (Las Campanas Obs., Pasadena, CA); LOCKWOOD, W.G. (Lowell Obs., Flagstaff, AZ)
The Surface Morphology of Solar-Type Hyades Stars
165th Am. Astron. Soc. Mtg., Tucson, AZ (13-16 January 1985)

REDUS, R.H., GUSSENHOVEN, M.S. (AFGL); and BASS, J.N. (RADEX, Inc., Carlisle, MA)
Adiabatic Variations in Ring Current Populations Observed by the SCATHA Satellite Between 5.5 and 8.5 RE
European Geophys. Soc. XI Gen. Assbly., Kiel, FRG (21-30 August 1986)

REDUS, R.H., GUSSENHOVEN, M.S., RICH, F.J., and HARDY, D.A.
A Polar Arc Interval During the February 1986 Magnetic Storm
AGU Mtg., San Francisco, CA (8-12 December 1986)

REDUS, R.H., GUSSENHOVEN, M.S. (AFGL); YEH, H.-C. (Boston Coll., Newton, MA); and HEINEMANN, N. (Emmanuel Coll., Boston, MA)
Thermal Properties of Ions During an Intense Polar Cap Arc Event on 15 January 1983
AGU Mtg., Baltimore, MD (19-23 May 1986)

RICH, F.J., and DENIG, W.F.
Is the Mantle the Source of the Dayside Region O Field Aligned Current Sheet?
AGU Mtg., Baltimore, MD (27-31 May 1985)

RICH, F.J., and GUSSENHOVEN, M.S.
What is a Quiet Ionosphere? A Search for Region 1 Region 2 Field-Aligned Currents During Quiet Times
AGU Mtg., San Francisco, CA (8-12 December 1986)

RICH, F.J., GUSSENHOVEN, M.S., and HARDY, D.A.
Observations by the DMSP Satellites of the Energy Flow into the High Latitude Ionosphere
Internat. Symp. on Large-Scale Processes in the Ionosphere-Magnetosphere System, Boulder, CO (2-5 December 1986)

ROTHWELL, P.L.
A Model Relating Polar Cap Arcs and the Interplanetary Magnetic Field
Chapman Conf. on Solar Wind-Magnetosphere Coupling, Pasadena, CA (12-15 February 1985)
Polar Cap Arcs and the Interplanetary Magnetic Field
AGU Solar Wind Mtg., Pasadena, CA (12-15 February 1985)
An Empirical Relationship Between K_p and the Tail Lobe Magnetic Field
AGU Mtg., San Francisco, CA (3-8 December 1985)

ROTHWELL, P.L. (AFGL); and SILEVITCH, M.B. (Northeastern Univ., Boston, MA)
Nonlinear Particle Precipitation Events - Simulation
AGU Mtg., San Francisco, CA (8-12 December 1986)

ROTHWELL, P.L. (AFGL); BLOCK, L.P. (Royal Inst. of Tech., Stockholm, Sweden); and SILEVITCH, M.B. (Northeastern Univ., Boston, MA)
Models for the Formation of the Substorm Current Wedge
AGU Mtg., San Francisco, CA (5-10 December 1985)

ROTHWELL, P.L. (AFGL); SILEVITCH, M.B. (Northeastern Univ., Boston, MA); and BLOCK, L.P. (Inst. of Tech., Stockholm, Sweden)
A Simple Model for the Substorm Current Wedge
COSPAR Mtg., Toulouse, France (30 June-12 July 1986)
A Model for the Dynamics of the Westward Traveling Surge
Wkshp. on Magnetospheric/Ionospheric Plasma Models, Huntsville, AL (13-16 October 1986)

RUBIN, A. (AFGL); TAUTZ, M., and COOKE, D. (RADEX Corp., Carlisle, MA)
Mesothermal Flow Codes
AGU Mtg., Baltimore, MD (19-22 May 1986)
Charging in an Auroral Environment
AGU Mtg., San Francisco, CA (8-12 December 1986)

RUBIN, A.G., HEINEMANN, M. (AFGL); TAUTZ, M., and COOKE, D. (RADEX Corp. Carlisle, MA)
Computer Models of the Spacecraft Walk
Conference on Space Plasma Issues in 2001, JPL, Pasadena, CA (1986)

SAGALYN, R.
Space Background, Physics and Implications for Future Systems
SPIE Mtg., Arlington, VA (8-12 April 1985)
DoD Support of the Space Sciences
AGU Mtg., Baltimore, MD (27-31 May 1985)

SCHUMAKER, T.L. (Boston Coll., Newton, MA); GUSSENHOVEN, M.S., HARDY, D.A. (AFGL); and CAROVILLANO, R.L. (Boston Coll., Newton, MA)
Study of ECH Wave Effects on Low Energy Plasma Sheet Electrons
AGU Mtg., Baltimore, MD (19-23 May 1986)

SHEA, M.A. (AFGL); and DRYER, M. (NOAA, Boulder, CO)
Overview of STIP Intervals I-XIV
STIP Symp. on Retrospective Analyses and Future Coordinated Intervals, Les Diablerets, Switzerland (10-12 June 1985)

SHEA, M.A., and SMART, D.F.
Energetic Particle Radiation Environment in Space
3rd An. Symp. on Single Event Effects, Los Angeles, CA (5-6 March 1985)
Scientific Results Obtained During STIP Intervals I and II
STIP Symp. on Retrospective Analyses and Future Coordinated Intervals, Les Diablerets, Switzerland (10-12 June 1985)
An Assessment of the Energetic Particle Environment
4th An. Symp. on Single Event Effects, Los Angeles, CA (8-9 April 1986)

SHEA, M.A., SMART, D.F. (AFGL); and GENTILE, L.C. (Emmanuel Coll., Boston, MA)
Estimating Cosmic Ray Vertical Cutoff Rigidities as a Function of the McIlwain L-Parameter for Different Epochs of the Geomagnetic Field
Fifth Scientific Assbly. of the Internat. Assoc. of Geomagnetism and Aeronomy (5-17 August 1985)

SHEA, M.A., SMART, D.F. (AFGL); SWINSON, D.B. (The Univ. of New Mexico, Albuquerque, NM); and HUMBLE, J.E. (Univ. of Tasmania, Hobart, Tasmania, Australia)
North/South Asymmetry in Solar Activity as Determined by the Comprehensive Flare Index
19th ESLAB Symp. of the Sun and the Heliosphere in Three-Dimensions, Les Diablerets, Switzerland (4-6 June 1985)

SHINE, R.A. (Lockheed Research Lab., Palo Alto, CA); and SIMON, G.W. (AFGL)
White Light Observations of a Sunspot Penumbra and Its Interaction with the Surrounding Photosphere
168th Am. Astron. Soc. Mtg., Ames, IA (June 1986)

SHUMAN, B.M., COHEN, H.A. (AFGL); HYMAN, J., ROBSON, R.R., and WILLIAMSON, W.S. (Hughes Research Lab., Malibu, CA)
A Charge Control System for Spacecraft Protection
Internat. Aerospace and Ground Conf. on Lightning and Static Electricity, Paris, France (10-12 June 1985)

SHUMAN, B.M., COHEN, H.A. (AFGL); HYMAN, J., ROBSON, R.R., SANTORU, J., and WILLIAMSON, W.S. (Hughes Research Lab., Malibu, CA)
Automatic Charge Control System for Geosynchronous Satellites
AGARD Symp. on Aerospace Environment at High Altitudes and Its Implications for Spacecraft Charging and Communications, The Hague, Netherlands (2-6 June 1986)

SILEVITCH, M.B. (Northeastern Univ., Boston, MA); and ROTHWELL, P.L. (AFGL)
Nonlinear Particle Precipitation Events-Theory
AGU Mtg., San Francisco, CA (8-12 December 1986)

SILEVITCH, M.B. (Northeastern Univ., Boston, MA); ROTHWELL, P.L. (AFGL); and BLOCK, L.P. (Royal Inst. of Tech., Stockholm, Sweden)
On the Structure of Pi 2 Wave Forms During Substorms
COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

SIME, D.G., FISHER, R.R. (High Altitude Obs., Boulder, CO); and ALTROCK, R.C. (AFGL)
Results from the Coronal Photometry Progam at NSO, II: Rotation of the Green Corona over the Solar Cycle
AAS Solar Phys. Div. Conf., Tucson, AZ (13-15 May 1985)

SIMON, G.W.
Measurements of Large Scale Flows on the Sun from SOUP
Scientific Results from Spacelab 2, Annapolis, MD (20-22 October 1986)

SIMON, G.W. (AFGL); SCHMIDT, H.U. (Max Planck Institut für Astrophysik, FRG); and WEISS, N.O. (Univ. of Cambridge, UK)
3-D Behavior of Buoyant Magnetic Flux Tubes in Granules and Supergranules
AAS Solar Phys. Div. Mtg., Tucson, AZ (May 1985)

SIMON, G.W. (AFGL); TITLE, A.M., TARBELL, T.D. (Lockheed, Palo Alto, CA)
Results from the Soup Experiment
COSPAR Meeting, Toulouse, France (30 June - 12 July 86)

SINGER, H.J.
AFGL Magnetometer Network Pulsation Observations
Mtg. on Hydromagnetic Waves in the Earth's Magnetospheric Plasma, New York, NY (17-18 October 1985)

SINGER, H.J., and ROTHWELL, P.L.
Ring Current Effects on Magnetospheric Magnetic Field Geometry and Standing Alfven Wave Eigenperiods
AGU Mtg., San Francisco, CA (8-12 December 1986)

SINGER, H.J., KNECHT, D.J. (AFGL); and GELPI, C. (Boston Univ., Boston, MA)
Substorm Associated Pulsations and Auroral Boundaries
AGU Mtg., San Francisco, CA (9-13 December 1985)
Substorm Associated Pulsations (Pi 2 and Pi 1) and Auroral Boundaries
5th Scientific Assbly. of IAGA, Prague, Czechoslovakia (5-17 August 1985)

SMART, D.F., SHEA, M.A. (AFGL); and LEBLANC, Y. (Observatoire de Paris, France)
Kilometric Type II Radiation Observed by the Voyager Spacecraft and Shockwaves During April 1978
AGU Mtg., San Francisco, CA (9-13 December 1985)

SMIDDY, M., DONATELLI, D., and BURKE, W.J.
Preliminary Plasma and Wave Measurements from the BERT-1 Rocket During Electron Beam Emissions
AGU Mtg., San Francisco, CA (9-13 December 1985)

SMITH, J.B., MACHADO, M., HAGYARD, M.J. (Marshall Space Flight Ctr., AL); NEIDIG, D.F. (AFGL)
Flare Activity, Sunspot Motions, and the Evolution of Vector Magnetic Fields in Hale Region 17244 (November 1980)
COSPAR Mtg., Toulouse, France (30 June - 12 July 1986)

SVESTKA, Z. (Lab. for Space Res., Utrecht, The Netherlands); FONTENIA, J.M. (CNIE, San Miguel, Argentina); MACHADO, M.E. (NASA Marshall Space Flight Ctr., Huntsville, AL); MARTIN, S.F. (California Inst. of Tech., Pasadena, CA); NEIDIG, D.F. (AFGL); and POLETTO, G. (Osservatorio astrofisico di Arcetri, Firenze, Italy)
A Dynamic Flare with Anomalously Dense Post-Flare Loops
COSPAR Mtg., Toulouse, France (30 June 1986)

SYDORA, R.D. (Univ. of California, Los Angeles, CA); and DONATELLI, D.E. (AFGL)
Electron Beam-Driven Ion Modes in a Space Plasma - Part I - Observations Electron Beam-Driven Ion Modes in a Space Plasma - Part II - Computer Simulations
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

TANSKANEN, P.J. (Univ. of Oulu, Oulu, Finland); and ROTHWELL, P.L. (AFGL)
The Velocity and Direction of the Westward Traveling Surge
AGU Mtg., Baltimore, MD (27-31 May 1985)

TANSKANEN, P.J., KANGAS, J., BOSINGER, T. (Univ. of Oulu, Oulu, Finland); and ROTHWELL, P.L. (AFGL)
Multiple WTS During a Substorm Expansion Phase Event Study
COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

TARBELL, T.D., TITLE, A.M. (Lockheed Research Lab., Palo Alto, CA); SIMON, G.W. (AFGL)
Videodisk Movies of the Solar Photosphere from the SOUP Instrument on Spacelab 2
168th Am. Astron. Soc. Mtg., Ames, IA (22-26 June 1986)

TITLE, A.M., TARBELL, T.D. (Lockheed Research Lab., Palo Alto, CA); and SIMON, G.W. (AFGL)
Measurements of the Lifetimes of Individual Granules from SOUP Data
168th Am. Astron. Soc. Mtg., Ames, IA (22-26 June 1986)

TOPKA, K.P., TARBELL, T.D. (Lockheed Research Lab., Palo Alto, CA); and SIMON, G.W. (AFGL)
Properties of Solar Granulation in Magnetic Versus Non-Magnetic Regions
168th Am. Astron. Soc. Mtg., Ames, IA (22-26 June 1986)

TYLER, S. (JPL, Pasadena, CA); EVANS, D. (Lockheed, Palo Alto, CA); and DENIG, W. (AFGL)
Quantitative Model of Auroral Charging Environment
Shuttle Environment and Operations II Conf., Houston, TX (13-15 November 1985)

YEH, H.-C. (Boston Coll., Newton, MA); and GUSSENHOVEN, M.S. (AFGL)
DMSP Eclipse Charging - The Statistical Electron Environment
AGU Mtg., Baltimore, MD (19-23 May 1986)

YEH, H.-C., HEINEMANN, N., CAROVILLANO, R.L. (Boston Coll., Newton, MA); GUSSENHOVEN, M.S., and HARDY, D.A. (AFGL)
Energy Dispersion of Precipitating Auroral Ions
AGU Mtg., San Francisco, CA (8-12 December 1986)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

BASINSKA, E.M., BURKE, W.J., BASU, S., RICH, F.J., and FOUGERE, P.F.
Low Frequency Modulation of Plasmas and Soft Electron Precipitation Near the Dayside Cusp
AFGL-TR-86-0226 (October 1986), ADA176894

CLIVER, E.W. (AFGL); MCNAMARA, L.F., (Ionospheric Prediction Service, Darlinghurst, New South Wales, Australia); and GENTILE, L.C. (Emmanuel Coll., Boston, MA)
Peak-Flux-Density Spectra of Large Solar Radio Bursts and Proton Emission from Flares
AFGL-TR-85-0180 (19 August 1985), ADA164458

DENIG, W.F. (AFGL); and FREDERICKSON, A.R. (RADC/ESRE, Hanscom AFB, MA)
Deep-Dielectric Charging - A Review
AFGL-TR-85-0123 (24 May 1985), ADA172204

DUBS, C.W., and HEINEMANN, M.
An Analytic Theory for Trajectories and Current to a Cylinder in a Flowing Magnetoplasma
AFGL-TR-85-0301 (22 November 1985), ADA169745

GAUNT, D.N.
Automated System for Resolving the Position of Solar Radio Bursts
AFGL-TR-85-0179 (19 August 1985), ADA164425

GUSSENHOVEN, M.S.
Electron and Ion Distributions at High Latitudes as Measured by the Air Force Polar Orbiting Satellites
AFGL-TR-85-0021 (26 February 1985), ADA153242

GUSSENHOVEN, M.S., MULLEN, E.G., and SAGALYN, R.C.,editors
CRRES/SPACERAD Experiment Descriptions
AFGL-TR-85-0017 (24 January 1985), ADA160504

GUSSENHOVEN, M.S., FILZ, R.C., LYNCH, K.A., MULLEN, E.G.(AFGL); AND HANSER, F.A. (Panametrics, Inc., Waltham, MA)
Space Radiation Dosimeter SSJ for the Block 5D/Flight 7 DMSP Satellite: Calibration and Data Presentation*
AFGL-TR-86-0065 (20 March 1986), ADA172178

HEINEMANN, M.
Shuttle Contamination Modeling: The Plasma Wave Field of Spacecraft
AFGL-TR-85-0300 (22 November 1985), ADA166605
Shuttle Contamination Modeling: Evolution of Ionized Shuttle Exhaust
AFGL-TR-86-0023 (22 January 1986), ADA172001

HEINEMANN, M., RUBIN, A. (AFGL); TAUTZ, M., and COOK, D. (RADEX Corp., Carlisle, MA)
Computer Models of the Spacecraft Wake
AFGL-TR-86-0160 (24 July 1986), ADA176881

KNECHT, D.J.
Daily Magnetograms for 1978 from the AFGL Network
AFGL-TR-85-0027 (8 January 1985), ADA168759
Daily Magnetograms for 1979 from the AFGL Network
AFGL-TR-85-0028 (22 February 1985), ADA173658
Daily Magnetograms for 1980 from the AFGL Network
AFGL-TR-85-0029 (22 February 1985), ADA169470
Daily Magnetograms for 1981 from the AFGL Network
AFGL-TR-85-0030 (28 February 1985), ADA173958
Daily Magnetograms for 1982 from the AFGL Network
AFGL-TR-85-0031 (1 March 1985), ADA173742
Daily Magnetograms for 1983 from the AFGL Network
AFGL-TR-85-0032 (21 March 1985), ADA173765

LAI, S.T., COHEN, H.A. (AFGL); and MCNEIL, W.J. (RADEX Corp., Carlisle, MA)
Spacecraft Sheath Modification During Beam Ejections
AFGL-TR-85-0215 (11 September 1985), ADA 166604

MCNEIL, W.J. (RADEX, Inc., Carlisle, MA); and SINGER, H.J. (AFGL)
Fluxgate Magnetometer Analysis and Simulation Software for the Combined Release and Radiation Effects Satellite (CRRES)
AFGL-TR-86-0222 (1 October 1986), ADA176353

RICH, F.J., and SMIDDY, M.
Plasma Densities and Irregularities at 830 KM Altitude Based on Observations During 1979
AFGL-TR-86-0121 (28 May 1986), ADA172118

RUBIN, A.G. (AFGL); and TAUTZ, M. (RADEX Corp., Carlisle, MA)
Calculation of Threshold Conditions for Materials Charging in Maxwellian Plasmas
AFGL-TR-85-0020 (25 January 1985), ADA157123

SHEA, M.A., MILITELLO, S.A. (AFGL); COFFEY, H.E., and ALLEN, J.H. (NESDIS, NOAA, Boulder, CO)
Directory of Solar-Terrestrial Physics Monitoring Stations - Edition 2
AFGL-TR-84-0227 (6 September 1984), ADA162395

SPIEGEL, S.L. (Univ. of Lowell, Lowell, MA); and COHEN, H.A. (AFGL)
Real Time, Automatic Vehicle Potential Determination from ESA Measurements. Part II. The Distribution Function Algorithm
AFGL-TR-85-0103 (II) (6 May 1985), ADA162072

SPIEGEL, S.L. (Univ. of Lowell, Lowell, MA); RAISTRICK, R.J. (AFGL); SAFLEKOS, N.A. (South-west Research Inst., San Antonio, TX); GUSSENHOVEN, M.S., and COHEN, H.A. (AFGL)
Real Time, Automatic Vehicle Potential Determination from ESA Measurements. Part I. The Count Ratio Algorithm
AFGL-TR-85-0103 (I) (8 May 1985), ADA160459

CONTRACTOR PUBLICATIONS JANUARY, 1985 - DECEMBER 1986

BATES, D.R. (Queen's Univ., Belfast, N. Ir.)
Deduction of Low Density Limit to Rate of Ter-molecular Ion- Molecule Association Measurement
J. Chem. Phys 84 (June 1986)
Heavy Ozone in the Stratosphere
Geophys. Res. Lett., 13 (July 1986)
Some Ter-Molecular Association Processes in Collisions of CH_j and Its Deuterated Analogs With H_2, HD, and D_2
J. Chem. Phys. 85 (1986)
Products of Dissociative Recombination of Polyatomic Ions
Astrophys. J. 306 (1986)

CHRISTENSEN-DALSGAARD, J., GOUGH, D., and TOOMRE, J. (Univ of Colorado, Boulder, CO)
Seismology of the Sun
Science 229 (6 September 1985)

CODONA, J.L. (Univ. of California, LaJolla, CA)
The Scintillation Theory of Eclipse Shadow-Bands
Astron. Astrophys. 164 (1986)

COLES, W.A., and FILICE J.P. (Univ. of California, LaJolla, CA)
Changes in the Microturbulence Spectrum of the Solar Wind During High-Speed Streams
J. Geophys. Res. 90 (1 June 1985)

DICKE, R.H., KUHN, J.R., LIBBRECHT K.G. (Princeton Univ., Princeton, NJ)
The Variable Oblateness of the Sun: Measurements of 1984
Astrophys. J. 311 (15 December 1986)

DOWDY, J.F., JR., MOORE, R.L., and WU, S.T. (Univ. of Alabama in Huntsville, AL)
Inhibition of Conductive Heat Flow by Magnetic Constriction in the Corona and Transition Region: Dependence on the Shape of the Constriction.
Solar Physics 99 (1985)

EMSLIE, A.G. (Univ. of Alabama in Huntsville, AL)
The Structure and Response of the Chromosphere to Radiation Backwarming During Solar Flares in *The Lower Atmosphere of Solar Flares*
Proceedings of the National Solar Observatory/ Solar Maximum Mission Symposium, D.F. Neidig, ed. (February 1986)

GREEN, B.D. (Physical Sciences, Inc., Andover, MA)
Review of the Vehicle Glow
AIAA Shuttle Environment and Operations II Conf. (13-15 November 1985)

GREEN, B.D., RAWLINS, W.T. and MARINELLI, W.J. (Physical Sciences, Inc. Andover, MA)
Chemiluminescent Processes Occurring Above Shuttle Surfaces
Planet. Space Sci 34 (1986)

HURLBURT, N.E., TOOMRE, J., and MASSAGUER, J.M. (Univ. of Colorado, Boulder, CO)
Two-Dimensional Compressible Convection Extending Over Multiple Scale Heights
Astrophys. J. 282 (15 July 1984)

JACKSON, B.V. (Univ. of California, La Jolla, CA)
Helios Observations of the Earthward- Directed Mass Ejection of 27 November 1979
Solar Phys. 95 (1985)
IPS and Spacecraft Observations of the 14 August 1979 Mass Ejection Transient in *STIP Symp. on Solar/Interplanetary Intervals*
ed. by M.A. Shea, D.F. Smart, and S.M.P. McKenna-Lawlor, Book Crafters (1984)
Imaging of Coronal Mass Ejections by the Helios Spacecraft
Solar Phys. 100 (1985)
Helios Images of Coronal Mass Ejections in *The Sun and Heliosphere in Three Dimensions*
ed. by R.G. Marsden, D. Reidel Pub. Co. (1986)
A Metric Type III Burst Asymmetry Relative to Simple Bipolar Active Regions
Solar Phys. 105 (1986)

JACKSON, B.V., and LEMBERT, C. (Univ. of California, La Jolla, CA)
Helios Images of Solar Mass Ejections
J. Geophys. Res. 90 (1 November 1985)

JACKSON, B.V., HOWARD, R.A., SHEELEY, N.R., JR., MICHELS, D.J., KOOMEN, M.J., and ILLING, R.M.E. (Univ. of California, La Jolla, CA)
Helios Spacecraft and Earth Perspective Observations of Three Loop-Like Solar Mass Ejection Transients
J. Geophys. Res. 90 (1 June 1985)

KAHLER, S.W. (Emmanuel Coll., Boston, MA); LIN, R.P. (Univ. of California, Berkeley, CA); REAMES, D.V., STONE, R.G. (Goddard Space Flight Ctr., Greenbelt, MD); and LIGGETT, M. (California Inst. of Tech., Pasadena, CA)
Solar Source Regions of ^{3}He-Rich Particle Events
19th Internat. Cosmic Ray Conf. Papers 4 (1985)

KUHN, J.R., LIBBRECHT, K.G., and DICKE, R.H. (Princeton Univ., Princeton, NJ)
Observations of a Solar Latitude-Dependent Limb Brightness Variation
Astrophys. J. 290 (15 March 1985)

LEIBACHER, J.W., NOYES, R.W., TOOMRE, J., and ULRICH, R.K. (Univ. of Colorado, Boulder, CO)
Helioseismology
Scientific American (September 1985)

LIBBRECHT, K.G., and KUHN, J.R. (Princeton Univ., Princeton, NJ)
A New Measurement of the Facular Contrast Near the Solar Limb
Astrophys. J. 27 (15 February 1985)

MACHADO, M.E., EMSLIE, A.G. (Univ. of Alabama in Huntsville, AL) and MAUAS, P.J.
A Mechanism for Deep Chromospheric Heating During Solar Flares
Astron. Astrophys. 159 (April 1986)

MASSAGUER, J.M., LATOUR, J., TOOMRE, J., and ZAHN, J.-P. (Univ. of Colorado, Boulder, CO)
Penetrative Cellular Convection in a Stratified Atmosphere
Astron. Astrophys. 140 (1984)

PORTER, J.G., TOOMRE, J., and GEBBIE, K.B. (Univ. of Colorado, Boulder, CO)
Frequent Ultraviolet Brightenings Observed in a Solar Active Region with Solar Maximum Mission
Astrophys. J. 283 (15 August 1984)

SONG, M.T., and WU, S.T. (Univ. of Alabama in Huntsville, AL)
On the Heating Mechanism of Magnetic Flux Loops in the Solar Atmosphere in Advances in Space Research 4 (1985)

VAN NES, P., ROELOF, E.C., REINHARD, R., SANDERSON, T.R., and WENZEL, K.-P. (The Johns Hopkins Univ., Laurel, MD)
A Major Shock-Associated Energetic Storm Particle Event Wherein the Shock Plays a Minor Role
J. Geophys. Res. 90 (1 May 1985)

WU, S.T. (Univ. of Alabama in Huntsville, AL)
Numerically-Simulated Formation and Propagation of Interplanetary Shocks in Computer Simulation of Space Plasmas,
ed. by H. Matsumoto and T. Sato.
Terra Scientific Publishing Co., Tokyo, and D. Reidel Pub. Co. (1984)

WU, S.T., WANG, J.F. (Univ. of Alabama, Huntsville, AL) and TANDBERG-HANSSEN, E. (NASA Marshall Space Flight Center)
MHD Analysis of the Evolution of Solar Magnetic Fields and Currents in an Active Region in *Unstable Current Systems and Plasma Instabilities in Astrophysics*
Proc. of the International Astronomical Union ed. by M.R. Kundu and G.D. Holman (1985).

CONTRACTOR TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

AKASOFU, S.-I., and FRY, C.F. (Univ. of Alaska, Fairbanks, AK)
A Three-Year Plan to Develop a Geomagnetic Storm Prediction Scheme for the OTH-B System
AFGL-TR-85-0152 (June 1985), ADA161651

AKASOFU, S.-I., and LEE, L.-C. (Univ. of Alaska, Fairbanks, AK)
A Study of the Relationship Between Solar Activity and Interplanetary Field Variations
AFGL-TR-86-0032 (February 1986), ADA169983

ASHOUR-ABDALLA, M., COLEMAN, P.J., DAWSON, J.M., GEKELMAN, W., KENNEL, C.F., DEBOEUF, J.N., OKUDA, H., STENZEL, R., and WALKER, R.J. (Univ. of California, Los Angeles, CA)
Acceleration Processes in the Earth's Magnetosphere
AFGL-TR-85-0143 (17 May 1985), ADA170506

BARFIELD, J.N. (Southwest Research Inst., San Antonio, TX)
Magnetospheric Plasma Studies Using Data from the Dynamics Explorer High and Low Altitude Plasma Instruments
AFGL-TR-86-0034 (February 1986), ADA169010

BRIDGE, H.S., and BINSACK, J.H. (Massachusetts Inst. of Tech., Cambridge, MA)
Definition Study of a Coordinated Group of Experiments to Measure and Monitor the In Situ Plasma and Electromagnetic Environment of a Polar Orbiting Space Shuttle
AFGL-TR-85-0238 (September 1985), ADA164561

CALEDONIA, G.E., PERSON, J.C. (Physical Sciences, Inc., Andover, MA); and HASTINGS, D. (Massachusetts Inst. of Tech., Cambridge, MA)
Ionization Phenomena about the Space Shuttle
AFGL-TR-86-0045 (January 1986), ADA170542

CARINI, P., KALMAN, G., and PULSIFER, P. (Boston Coll., Newton, MA)
Neutral Beam Propagation Effects in the Upper Atmosphere
AFGL-TR-85-0038 (1 October 1984), ADA174896

CAROVILLANO, R.L. (Boston Coll., Newton, MA)
Large Spacecraft in the Magnetospheric Environment
AFGL-TR-86-0134 (26 June 1986), ADA175490

COOKE, D.L., and KATZ, I. (S-Cubed, La Jolla, CA)
Ionization Induced Instability in an Electron Collecting Sheath
AFGL-TR-85-0256 (June 1985), ADA165330

DAVIS, J.M., and WEBB, D.F. (American Science and Engineering, Inc., Cambridge, MA)
A Study of the Cyclical Variations of Coronal Holes and Their Relation to Open Magnetic Fields
AFGL-TR-85-0003 (December 1984), ADA155251

DEININGER, W.D., ASTON, G., and PLESS, L.C. (Jet Propulsion Lab., Pasadena, CA)
A Neutral Plasma Source for Active Spacecraft Charge Control
AFGL-TR-85-0313 (August 1985), ADA165223

DEVANE, J.F., S.J. (Boston Coll., Newton, MA)
Investigation of Magnetic Field Measurements
AFGL-TR-85-0054 (15 March 1985), ADA157924

DRYER, M. (NOAA/ERL, Boulder, CO)
Magnetohydrodynamic Modelling of Solar Disturbances in the Interplanetary Medium
AFGL-TR-86-0161 (December 1985), ADA172176

DRYER, M., SMITH, Z.K., DETMAN, T.R., and YEH, T. (NOAA/ERL, Boulder, CO)
MHD Simulation of the Interplanetary Environment in the Ecliptic Plane During the 3-9 February 1986 Solar and Geomagnetic Activity
AFGL-TR-86-0189 (September 1986), ADA173822

DYER, G. (Kimball Physics, Inc., Wilton, NH)
High-Current Electron Gun for Space Flight
AFGL-TR-86-0217 (31 August 1986), ADA 179287

ELGIN J.B., and SUNDBERG, R.L. (Spectral Sciences, Inc., Burlington, MA)
Development of a Monte Carlo Shuttle Contamination Model
AFGL-TR-86-0204 (30 September 1986), ADA175409

GREENSPAN, M.E., ANDERSON, P.B., and PELAGATTI, J.M. (Regis Coll., Weston, MA)
Characteristics of the Thermal Plasma Monitor (SSIES) for the Defense Meteorological Satellite Program (DMSP) Spacecraft S8 Through S10
AFGL-TR-86-0227 (30 October 1986), ADA 176924

HILL, G.C. (California Inst. of Tech., Pasadena, CA)
Interactions Measurement Payload for Shuttle (IMPS) Definition Phase Study - Final Report
AFGL-TR-85-0023 (15 December 1984), ADA165222

HILLS, R.S. (TRI-CON Assoc., Inc., Cambridge, MA)
Refurbishment of an Ultraviolet and Electronic Spectrometer and Photometer
AFGL-TR-85-0105 (29 April 1985), ADA160363
Design Sounding Rocket Payload System to Study Vehicle Charging Phenomena
AFGL-TR-85-0131 (29 May 1985), ADA162149
Design, Fabricate and Test Spacecraft Automatic Active Discharge Systems (SAADS)
AFGL-TR-85-0236 (25 September 1985), ADA166559

HURFORD, G.J. (California Inst. of Tech., Pasadena, CA)
Application of Microwave Spectroscopy to the Study of Coronal Field Changes Associated with a Disappearing Sunspot
AFGL-TR-85-0092 (March 1985), ADA162191

JACKSON, B.V., and RICKETT, B.J. (Univ. of California, La Jolla, CA)
Use of Interplanetary Scintillation for Earth Space Environment and Geomagnetic Forecasting
AFGL-TR-85-0124 (April 1985), ADA161621

KAHLER, S., REAMES, D.V., SHEELEY, N.R., JR., HOWARD, R.A., KOOMEN, M.J., and MICHELS, D.J. (Emmanuel Coll., Boston, MA)
A Comparison of Solar ³Helium-Rich Events with Type II Bursts and Coronal Mass Ejections
AFGL-TR-85-0205 (1 July 1985), ADA161595

KARPEN, J.T. (Naval Research Lab., Washington, DC)
A Search for Precursor Activity Associated with Coronal Mass Ejections, Using White-Light Coronagraph Observations Obtained with the SOLWIND Instrument on Board the Air Force P78-1 Satellite
AFGL-TR-86-0056 (31 December 1985), ADA170139

LAFRAMBOISE, J.G. (York Univ., Downsview, Ontario, Canada)
Predicting High-Voltage Charging of Spacecraft in Low Polar Orbit
AFGL-TR-85-0263 (30 March 1985), ADA166617
Progress Toward Predicting High-Voltage Charging of Spacecraft in Low Polar Orbit
AFGL-TR-86-0261 (28 October 1986), ADA 176939

LILLEY, J.R., JR., KATZ, I., and COOKE, D.L. (S-Cubed, La Jolla, CA)
The Roles of $V \cdot B$ and Density Gradients in Plasma Electric Fields Measured from the Shuttle Orbiter
AFGL-TR-85-0257 (June 1985), ADA165230

LILLEY, J.R., JR., COOKE, D.L., JONGEWARD, G.A., and KATZ, I. (S-Cubed, La Jolla, CA)
Polar User's Manual
AFGL-TR-85-0246 (October 1985), ADA173758

MOREL, P.R., HANSER, F.A., and SELLERS, B. (Panametrics, Inc., Waltham, MA)
Fabricate, Calibrate and Test a Dosimeter for Integration into the CRRES Satellite
AFGL-TR-85-0150 (II) (March 1985), ADA161695
Fabricate, Calibrate and Test a Dosimeter for Integration into the CRRES Satellite
AFGL-TR-86-0001 (III) (December 1985), ADA168566

NIGHTINGALE, R.W., CHIU, Y.T., DAVIDSON, G.T., FRANCIS, W.E., RINALDI, M.A., ROBINSON, R.M., and VONDRAK, R.R. (Lockheed Palo Alto Research Lab., Palo Alto, CA)
A Source Radiation Test Model Study
AFGL-TR-86-0064 (14 March 1986), ADA169412

NISENSON, P., STACHNIK, R.V., and NOYES, R.W. (Smithsonian Inst. Astrophysics Obs., Cambridge, MA)
Development of a CCD Based Solar Speckle Imaging System
AFGL-TR-86-0044 (I) (3 February 1986), ADA172219

RAITT, W.J. (Utah St. Univ., Logan, UT)
Modeling the F-Region of the High Latitude Ionosphere
AFGL-TR-86-0238 (7 November 1986), ADA 178383

ROBSON, R.R., and WILLIAMSON, W.S. (Hughes Research Lab., Malibu, CA)
Flight Model Discharge System
AFGL-TR-85-0041 (I) (March 1985), ADA160434

ROBSON, R.R., WILLIAMSON, W.S., and HYMAN, J. (Hughes Research Lab., Malibu, CA)
Positive Ion Ejection System (PIES)
AFGL-TR-85-0251 (September 1985), ADA166560

ROBSON, R.R., WILLIAMSON, W.S., and SANTORU, J. (Hughes Research Lab., Malibu, CA)
Flight Model Discharge System
AFGL-TR-86-0036 (II) (February 1986), ADA169423

SAMSON, J.C. (Univ. of Alberta, Edmonton, Alberta, Canada)
Development of Computer Programs and Related Software for the Detection and Analysis of Pi 2 or PI 2 Pulsations Recorded at Ground Based Stations
AFGL-TR-85-0146 (2 July 1985), ADA165224

SECAN, J.A. (Physical Dynamics, Inc., Bellevue, WA)
Development of Techniques for the Use of DMSP SSIE Data
AFGL-TR-85-0107 (20 April 1985), ADA 176412

STEINOLFSON, R.S. (Univ. of California, Irvine, CA)
Dynamic Formation of Stressed Coronal Magnetic Fields
AFGL-TR-86-0062 (February 1986), ADA170176

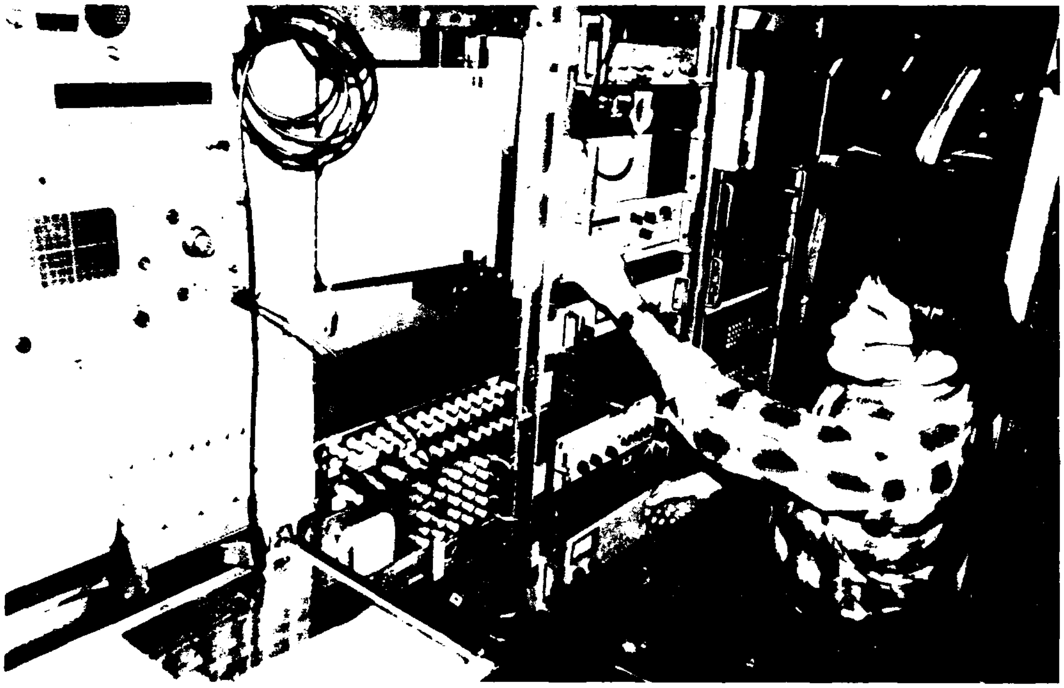
STEVENS, N.J., and KIRKPATRICK, M.E. (TRW, Inc., Redondo Beach, CA)
Spacecraft Environment Interaction Investigation
AFGL-TR-86-0214 (October 1986), ADA 179183

TARBELL, T.D. (Lockheed Missiles and Space Co., Inc., Palo Alto, CA)
Spectral Imaging with a CID Camera
AFGL-TR-85-0075 (22 March 1985), ADA161608

TSUNODA, R.T., SMITH, A.Q., KELLY, J.D., and ROBINSON, R.M. (SRI International, Menlo Park, CA)
Coordinated Radar and Satellite Studies of Ionospheric Currents in the Auroral Zone and Polar Cap
AFGL-TR-86-0022 (December 1985), ADA169466

WEIMER, D.R. (Regis Coll., Weston, MA); GURNETT, D.A., and GOERTZ, C.K. (Univ. of Iowa, Iowa City, IA)
The Conductance of Auroral Magnetic Field Lines
AFGL-TR-86-0225 (October 1986), ADA174047

WOLF, R.A. (Rice Univ., Houston, TX)
Computer Simulation of the Dynamics of the Near-Earth Part of the Geomagnetic Tail
AFGL-TR-86-0063 (20 March 1986), ADA169419



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III IONOSPHERIC PHYSICS DIVISION

Air Force communications and surveillance systems operate in the ionosphere, that region of the earth's upper atmosphere where charged particles play a dominant role in the physical and dynamical properties of the medium at altitudes between about 60 km and 1000 km. These particles change the path of all radio signals in the ionosphere. For this reason, AFGL measures the extreme ultraviolet radiation which creates the ionosphere, the interaction among the many charged-particle species present, and the electrical structure, electron concentration, total electron content, and ionic structure of the region.

The ultraviolet radiations in the upper atmosphere are the principal energy source driving the intensely dynamic structure and properties of the medium. Since missiles emit ultraviolet radiation, the technology developed to study the ionosphere can also be used to locate and identify missiles. Ionospheric studies can therefore be used to help solve problems in the areas of missile surveillance and tracking, spacecraft horizon sensing, atmospheric/ionospheric sensing for communication and detection purposes, and technical intelligence. Ultraviolet radiations are measured principally on board satellites, although rocket measurements have also proved very useful. The principal theoretical tools used to make these measurements are atomic and molecular quantum mechanics.

The propagation of radio waves in and through the upper atmosphere is profoundly influenced by the high concentration of charged particles. This concentration varies markedly during disturbed conditions such as scintillation, auroral precipitation events, and polar cap absorption events all of which can severely degrade the performance of satellite communications systems. The Ionospheric Physics Division observes these phenomena with a variety of instruments on the ground, on sounding rockets, on satellites, such as Polar BEAR, and on the Division's Airborne Ionospheric Observatory (AIO), an NKC-135 aircraft.

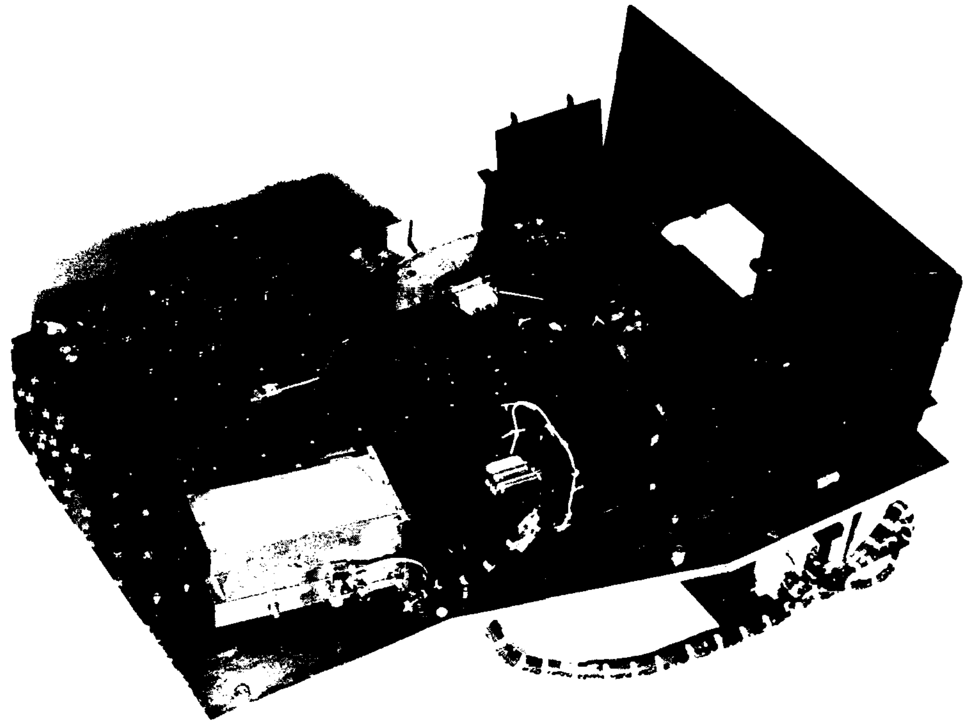
The many charged particle species, constantly being produced and subsequently destroyed, interact with one another in a great variety of two-, three-, and multiparticle encounters. Laboratory studies are employed to measure the reaction rates of these species, and theoretical work is conducted on models which attempt to simplify and explain the complicated development of the ionosphere and its plasma constituents. Results of these investigations are of direct interest to the Integrated Operational Nuclear Detection System of Space Division and to the Ballistic Missile Office.

An extensive program exists to investigate, both theoretically and experimentally, large-scale global ionospheric processes in regions such as the polar cap, the auroral oval, the F-layer trough, and the Appleton Anomaly. These large-scale structures result from extremely complex interactions among neutral winds and ionospheric plasma drifts driven by electric fields, various ions and precipitating particles. The large-scale features produce deleterious effects on Air Force systems operating principally in the hf range. The Division also investigates medium and small-scale processes with scale sizes from some tens of kilometers to a few centimeters that produce irregularities such as equatorial electron-concentration depletions, high-latitude ionosphere scintillation and the polar cap, F-layer auroras and patches. Various plasma instabilities are the cause of many medium and small-scale irregularities, while auroras are produced by strong local particle precipitation. Medium and small-scale irregularities adversely affect radio propagation in a wide range from hf through shf. Consequently, Air Force systems are adversely affected from the hf over-the-horizon back-scatter radar to the satellite communication systems (AFSATCOM, MILSATCOM) and the Global Positioning Satellite (GPS), operating over the whole uhf and part of the shf band. Many of these deleterious effects occurring naturally in the ionosphere would also be observed in a nuclear-disturbed ionosphere.

ULTRAVIOLET RADIATION

UV Imaging from Satellites: Ultraviolet radiation from the earth's ionosphere is being used to develop remote-sensing methods for determining the electron-density profile of the ionosphere and for locating the auroral disturbance region. These improved methods will enhance operation of Air Force communications and radar systems. The feasibility of identifying regions at high latitudes that produce radio-wave scintillation is also of interest, since these regions simulate the effects of high-altitude nuclear bursts.

After the proof-of-concept demonstration provided by the short-lived Auroral/Iono-



AIRS Sensor Launched November 13, 1986, on the Polar Orbiting Polar BEAR Satellite.

spheric Mapper experiment in 1983, an improved instrument, the Auroral/Ionospheric Remote Sensor (AIRS), was included on the Space Test Program Polar BEAR (Beacon and Auroral Research) satellite launched in November, 1986 (see the figure). AIRS produces four simultaneous strip-map images of optical radiation from the earth's ionosphere as viewed from 1000 km on the polar-orbiting stabilized satellite. An earth-facing movable mirror makes repetitive cross-track observations. When the resulting light-intensity measurements are displayed in proper registration with the ground, a map is produced.

Data for two of the four images are the output from a grating spectrometer which can be set to wavelengths in the 1100-1900 Å region. These two channels have a constant separation of 240 Å, spectral resolution of about 36 Å, and spatial resolution at nadir of about 5 by 20 km. For example, the atomic oxygen line at 1356 Å and a group of molecular nitrogen Lyman-Birge-Hopfield bands near 1596 Å can be measured to monitor the daytime airglow and aurora. Data for the other two images are the output of a pair of filter photometers which have about the same spatial resolution as the spectrometer channels. The filters for the photometers can be switched between a pair most useful at night (3914Å and 6300Å) and a pair most useful in daylight (2250Å and 3370Å). By mid-December 1986, Polar BEAR and the AIRS sensor had successfully completed post-launch check-out; at the end of December, routine operations were underway, and the first high-quality images were being readied for analysis.

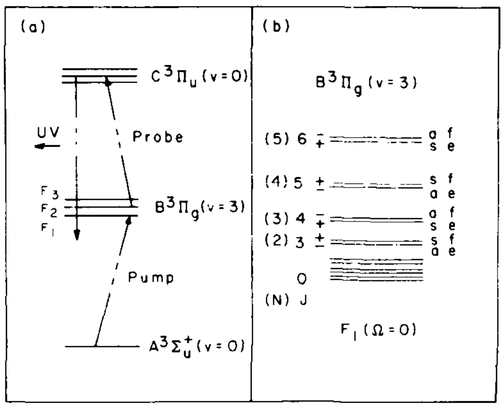
Applications of the AIRS results are diverse. At one extreme, they will provide moderately high spatial-resolution information on the characteristics of ultraviolet background radiation needed to evaluate missile defense concepts. At another extreme, they will supply the moderately high spectral-resolution information needed to test and validate codes being developed in this Division to enable passive remote topside sensing of electron density profiles. The ultimate use of this technique would be its application as the Special Sensor Electron density (SSE) on Defense Meteorological Satellite Program satellites.

UV Radiation of Missiles: For missile defense purposes, the ultraviolet radiations of missiles were measured as they were launched at Vandenberg AFB and also as they were fired in a test stand at the White Sands Missile Range. In February, 1985, a Titan III B having a large liquid engine was observed during launch at Vandenberg AFB. Radiant intensities, spectra, and spatial characteristics were measured. In October, 1985, two small solid boosters were observed while being fired in a test stand at White Sands. In March, 1986, a Peacekeeper and two Minuteman missiles were observed during launch at Vandenberg AFB, and in November, 1986, a Scout launch was observed at Vandenberg AFB at launch and up to altitudes of 50 km. The data obtained during these measurements have all been analyzed and published.

Solar UV Radiation: Data on solar ultraviolet absorption in the stratosphere, obtained from a balloon flight in April, 1983, were analyzed to obtain the transmission characteristics of the atmosphere in the ultraviolet window near 2000 Å, and in particular to establish more accurate values for the absorption spectrum of molecular oxygen. This analysis indicated that the atmosphere is more transparent than had been assumed on the basis of laboratory measurements. New calculations of the photodissociation rate coefficients for molecular oxygen were made using these data, demonstrating the creation of atomic oxygen and ozone at deeper levels in the stratosphere than the current models show.

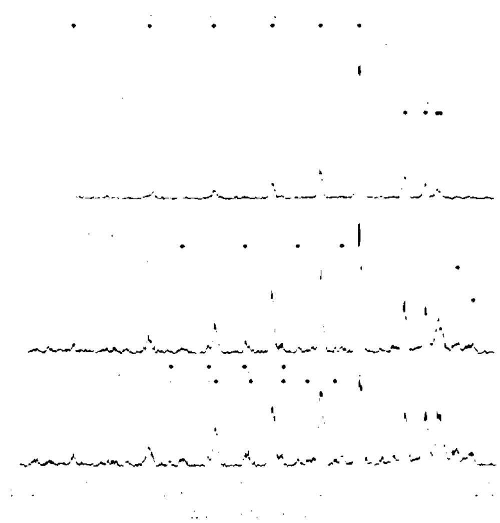
At the request of the Optical Physics Division, a spectrum was prepared of the solar radiation between 2000 Å and 3200 Å in 1 Å resolution, as measured at 40 km in the stratosphere in April, 1983. Extrapolation of these solar irradiance data to the top of the atmosphere provides a reference spectrum in higher spectral resolution than others currently available. Currently this spectrum is being considered for use in an update of AFGL's LOWTRAN optical transmission codes.

Laser Spectroscopy: Ultraviolet emissions occurring in the upper atmosphere have important remote-sensing and surveillance applications. Detailed knowledge must be obtained of the excitation and radiative quenching processes occurring in atmospheric molecules and ions in order to characterize and describe these emissions in complicated environments such as auroras and nuclear-perturbed atmospheres. A laboratory program using lasers is being conducted to determine electronic quenching processes and rates in atmospheric molecules and ions. It is surprising that very little is known about the collisional deactivation of electronically excited molecules. A number of experiments have been conducted to obtain information on the deactivation paths and rates which are important for predicting wavelengths of radiative emissions as well as for laser diagnostics.



The Pump Probe Experiment. (a) Schematic Diagram. (The probe laser's pulse can be varied in time with respect to that for the pump laser. The detected ultraviolet pulse is from the C^3 g(0,0) transition.) (b) Energy Level Diagram of the $B\pi g$ ($v = 3$, $\Omega = 0$) Rotational Manifold with e/f Parity Notation. (The manifold for the F^2 ($\Omega = 1$) and F^3 ($\Omega = 2$) spin components begins at approximately 45 and 90 cm^{-1}, respectively, above the $J = 0$ level of the $F_1(\Omega = 0)$ manifold.)

A two-laser, optical-optical double resonance (OODR) technique has been used as a direct probe of the rotational energy transfer (RET) in the electronically excited B state of molecular nitrogen. An energy level diagram illustrating the double resonance, "pump" - "probe" experiment is shown in part (a) of the figure. Part (b) shows details of the F_1 rotational manifold for the B ($v = 3$) state. The pump laser selectively populates a rotational level of the nitrogen B ($v = 3$) electronic state, and collision-induced RET from this selectively populated level to other levels of the rotational manifold is determined by scanning the probe laser through the C-B (0, 3) band. An example of a probe laser excitation spectrum is given in the next figure, where the pump laser selectively populates the $J = 0$, e level of the B (F_1) manifold and the probe laser scans the C-B (0, 3) band with delay times of approximately (a) 25, (b) 60, and (c) 90 ns. From scans such as these, propensity or "selection rules" were deduced for RET in the B state of nitrogen. We also found that RET is not faster than collision-



Probe Laser Spectrum of the $C^3\pi_u$ - $B^3\pi_g$ (0, 3) Band with a Delay of (a) 25 ns, (b) 60 ns, and (c) 90 ns from the Pump Laser. (The pump laser's wavelength is fixed so that the $J=0$ level of the $B^3\pi_g$ ($\Omega = 0$) is populated; thus $R_1(0)$ is expected to be the most intense line at short delay times.)

induced electronic energy transfer. Thus electronic transfer by collisions should have an important role in the emissions involving the nitrogen Vegard-Kaplan and first positive systems.

A double-resonance technique has also been used to obtain detailed information of electronic energy transfer between a single rotational level of the A state of N_2^+ and the nearly degenerate levels of an X state vibrational manifold. Such information could be used to compare experimental results with theoretical quantum mechanical calculations. This comparison showed qualitative agreement, although there is more experimental and theoretical work needed in this area. Finally, the ultraviolet Huggins band of ozone was reanalyzed to confirm a previous vibrational quantum number assignment for the antisymmetric stretch mode of the upper state of this band system.

IONOSPHERIC INTERACTIONS

In the ionosphere, the many ion and neutral species undergo a wide variety of encounters which affect radio propagation in this region. Such effects can be particularly acute at high latitudes. They also affect the environment of spacecraft in orbit and during re-entry.

A comprehensive network of polar ionospheric monitoring experiments has been assembled to conduct radio-wave propagation studies within the polar cap. Such topics as "polar cap absorption" and "meteor scatter" were studied with the aid of several installations in Greenland.

In addition, both the ion and neutral chemistry of the ionosphere have been studied theoretically as well as in laboratory and field experiments. Research in the chemistry of sodium in the lower portion of the ionosphere showed that the change of sodium vertical content with season is attributable to seasonal variations of the neutral chemistry of sodium. These studies provide insight into the behavior of O and O_3 in the mesosphere and thus also to a better understanding of D-region chemistry.

Research in ion chemistry centered on measurements of rate constants, cross sections, bond dissociation energies, and electron affinities for the reactions of ions in the gas phase with neutral molecules, electrons, photons, and other ions. These reactions cause, among other things, the radio blackout during atmospheric re-entry of spacecraft. The measured rate constants serve as input to computer codes developed to model the blackout conditions. Also, several chemicals have been investigated for their ability to react with free electrons in the gas phase to produce negative ions. A good electron-quenchant species is one that attaches electrons rapidly. The energy to detach the electron from the resulting negative ion must also be large. Strong acids have been identified as among the best electron quenchants. Such species can be used to produce effective and long-lasting perturbations of the local ionospheric electron densities.

Continued analysis of mass spectrometer data from a 1982 shuttle flight supports the claim that water vapor outgassing from shuttle surfaces is the most concentrated contaminant species from the shuttle and that a strong correlation exists between the intensity of the water and the temperature of the instrument and shuttle bay. Also, large differences between the measured composition and the calculated composition of the thruster exhaust plumes are attributed to kinematic effects.

Below the ionosphere lies the strato sphere, a region where electrons dominate the atmospheric-electric processes and where certain gaseous emissions from various Air Force operations have been evaluated in terms of their possible risk to the ozone layer. The positive ion composition of the stratosphere was determined from two balloon flights, which covered the altitude range from 29 km to 41 km. The on-board quadrupole mass spectrometer provided the positive ion mass distribution for ions of up to 1000 atomic mass units. Investigation of the neutral trace gas composition of the stratosphere was completed with the compilation and analysis of the oxides of nitrogen and inorganic bromine data.

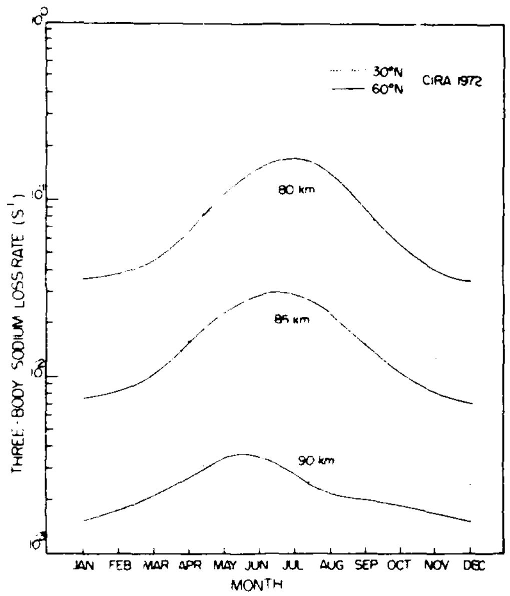
Polar Ionospheric Monitoring: Since June, 1986, we have been operating a comprehensive network of polar ionospheric monitoring experiments. These systems have been acquired and installed to conduct radio wave propagation studies within the polar cap, especially concentrating on effects created by severe ionospheric D-region disturbances such as polar cap absorption events created by solar proton events.

Several installations include a low-frequency grazing incidence ionosounder between Thule AB and Sondrestrom AB; and a modified meteor scatter communications link at 65 MHz, operating in parallel with the multifrequency test link. A scanning high-frequency propagation probe in parallel with scatter links will be implemented in 1987.

The meteor scatter multifrequency link operates on four frequencies: 45, 65, 104 and 147 MHz, to permit studies of the properties of meteor scatter communications as a function of frequency during normal and disturbed conditions. This is the initial effort in a planned continuing theoretical and experimental program to investigate the performance of meteor scatter propagation at high latitudes and to provide an improved understanding of the methodology needed to maximize the yield of future systems. Data acquired are analyzed to evaluate such parameters as trail availability, waiting times, and throughput as a function of modulation techniques. Propagation effects such as signal dispersion and Faraday rotation are also studied, since they are affected by disturbances of the ionosphere.

Other measurements of ionospheric effects are provided by the riometers, the low-frequency sounder, and the high-frequency propagation probe. Additional information will be drawn from a variety of related experiments conducted by AFGL, several Danish institutes, and other agencies, such as the ionosounder operated by the Ionospheric Physics Division in Qanaq and a number of riometers posted throughout Greenland. Specific comparisons will be made between the communications throughput of hf propagation and vhf meteor scatter links as a function of such measured parameters as ionospheric absorption, maximum usable hf frequency, ion-layer height, and electron density.

Chemistry of Metals in the Ionosphere: Significant progress was made in explaining seasonal patterns associated with the sodium layer in the upper mesosphere. Contrary to a number of past "guestimates" over the previous two decades, most sodium reactions appear to be quite rapid, i.e., they are of the same order of magnitude as the kinetic collision rate. There is an exception or two. The rapidity of the reactions simplifies analyses in the sense that below the peak of the sodium layer, nominally 90 km, the relative abundance of the sodium compounds (Na, NaO, NaO_2, and NaOH), may be derived from their (chemical) steady-state equations. Research has shown that sodium ions have little impact upon the overall pattern of sodium, except to reduce the Na scale height above 90 km because of the increasing conversion of Na to Na^+ with altitude above 90 km.



Annual Variation of Three-Body Loss Rate.

The change of sodium vertical content with season (more in winter) therefore appears to be attributable to seasonal variations of the neutral chemistry of sodium. From the figure we see that the main loss process for Na, $Na + O_2 + M \rightarrow NaO_2 + M$, where $M = O_2 + N_2$ changes with M and T in such a way as to favor an increase in the sodium content with winter. Other factors may contribute, most notably the slow reaction $NaO_2 + O \rightarrow NaO + O_2$. The rate coefficient has been estimated to be about 10^{-13} cm^3s^{-1} for this process. It will contribute significantly to the seasonal content variation of sodium if the rate constant is more like 10^{-10} exp(-1250/T), where T is the absolute temperature. An increase of atomic oxygen in winter versus summer also would contribute, since this loss process for NaO_2 involves [O]. The distribution of atomic oxygen in the mesosphere, which bears upon so many emission processes in this region, is poorly known as a function of season and latitude. There are very few reliable measurements of this very important minor constituent.

A confusing issue, namely that the seasonal variation observed for the column content of sodium is different from that of the nightglow, has been resolved. In recent years it has become almost certain that the sodium nightglow at 5893 Å (D-lines) from $^2P \rightarrow {}^2S$ transition in sodium arises from Chapman's mechanism.

$$Na + O_3 \rightarrow NaO + O_2$$

$$NaO + O \rightarrow Na\ (^2P,\ ^2S) + O_2$$

Both processes are fast and most certainly the first process is. It is the rate-limiting step for the volume emission rate E (photons $cm^{-3}s^{-1}$),

$$E = fk_1[O_3][Na]$$

where k_1 is the reaction rate coefficient for the $Na + O_3$ process, square-bracketed terms are species concentrations, and $f = 1/3$ is the fraction of sodium believed to be left in the excited ^2P state in the second of the two reactions above. This equation for E predicts that the emission is proportional to ozone concentration. Data obtained with the Solar Mesosphere Explorer (SME) satellite indicate that O_3 is a maximum near the equinoxes at midlatitudes. This fact is in accord with information gathered over many years which shows a similar pattern for the sodium nightglow. (The dayglow, which arises from the same chemiluminescent processes, is negligible compared to resonance scattering of 5893 Å solar radiation by sodium.)

We have argued that the different seasonal behaviors of the nightglow and vertical content arise from the fact that the fast process $Na + O_3 \rightarrow NaO + O_2$ effectively removes very little Na because $NaO + O \rightarrow Na + O_2$ is sufficiently fast. Hence, the three-body process introduced above, with rate constant k_3, is primarily responsible for converting sodium atoms to other compounds starting with NaO_2. The reaction $NaO_2 + O \rightarrow NaO + O_2$ with rate coefficient k_6, also followed by $NaO + O \rightarrow Na + O_2$, counters the role of the three-body process, but only somewhat, since the process is slow, as discussed above. In other words, we find roughly that

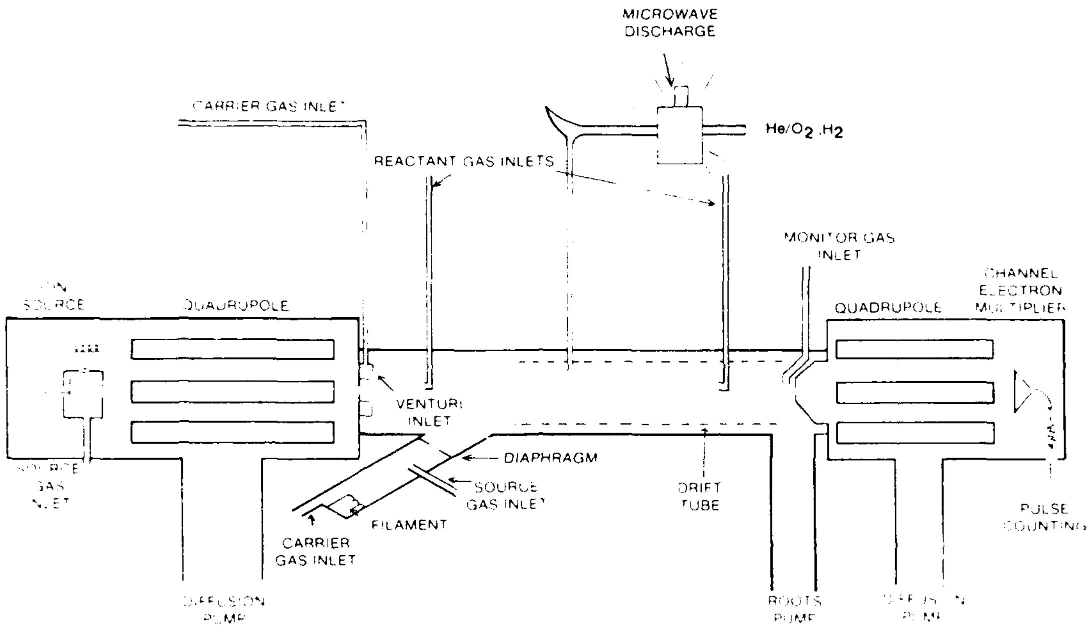
$$\frac{[Na]}{[NaO_2]} = \frac{k_6[O]}{k_3[O_2][M]}$$

below the peak of the sodium layer, showing that Na is not controlled as is E by the ozone concentration. However, there is some coupling inasmuch as the source for an increase in O_3 at these altitudes is loss of O through $O + O_2 + M \rightarrow O_3 + M$. On the other hand, the Chapman process remains the largest source of NaO, the precursor species for the nightglow.

Studies of the chemistry of sodium in the mesosphere can also help shed light upon the behavior in the mesosphere of O and O_3, gases important both to D-region chemistry and atmospheric emissions like the green line of atomic oxygen at 5577 Å and the OH (infrared) Meinel bands. In addition, the chemistry of sodium is important to missile exhaust chemistry, and by analogy to potassium chemistry, of interest in muzzle flash problems.

Atmospheric Ion Chemistry: The primary objective of the program in atmospheric ion chemistry is to obtain information on the reactions of ions in the gas phase with neutral molecules, electrons, photons, and other ions. These kinds of reactions are important in the stratosphere, mesosphere, and thermosphere, and under other conditions in which weak plasmas are generated, as in combustion and some gas-phase laser chemistry. Such phenomena as antenna breakdown, radio blackout during atmospheric reentry, and radio and radar blackout following nuclear detonations are in part the result of these reactions. The computer codes which have been developed to model these phenomena require as input the rate constants, cross sections, bond dissociation energies, and electron affinities.

Our studies on reactions between ions and neutral molecules are performed using a selected ion flow tube (SIFT). In the SIFT, reactant ions are generated either by electron bombardment or as the result of ion-neutral reactions. These ions are mass-analyzed, and the desired ion species is injected into a fast flowing (10^4 cms^{-1}) stream of inert carrier gas, usually helium. Further downstream, after the ions have reached the same temperature as that of the carrier gas, reactant neutral gas is injected into the flow tube at a known flow rate. Ion neutral reactions may then occur, usually causing depletion of the reactant ions and formation of product ion species. The ion composition of the gas stream is monitored with a second mass spectrometer at the downstream end of the flow tube. Reaction rate constants are determined by measuring the loss of reactant ions as the flow rate of the reactant neutral gas is varied. The temperature range available in these studies is from 85°K to about 600°K. Possible reactant neutral species include atomic hydrogen and atomic oxygen, in addition to more stable species. As a result of the



Selected Ion Flow Drift Tube. (Ions generated in the ion source are mass-selected with the quadrupole mass spectrometer on the left and injected into the flow-drift tube, which contains inert carrier gas flowing at high velocity. Alternatively, reactant ions may be injected without prior mass analysis through the diaphragm. Reactant neutral gas, which may include atomic hydrogen or atomic oxygen, is injected into the tube further downstream. The translational energy of the reactant ions can be controlled with the electric field in the drift tube. The ion composition of the flowing stream is analyzed with the mass spectrometer on the right.)

recent addition of a drift tube to the apparatus, converting the SIFT to a Selected Ion Flow Drift Tube (SIFDT), a longitudinal electric field can be generated in the reaction region of the flow tube, allowing the average ion kinetic energy to be varied (see the figure). By this means, translational energies corresponding to temperatures up to several thousand degrees Kelvin can be obtained. However, the internal energies of the ions and neutral molecules are not equilibrated with the translational energy of the ions, and the effects of very high temperature on reaction kinetics are only incompletely simulated.

The positive ion composition of the stratosphere is now known to be dominated by complex solvated ion species derived from such neutral molecules as water and acetonitrile, while the negative ion composition is dominated by solvated ion species involving water, sulfuric acid, hydrochloric acid, and nitric acid. The abundances of these species as neutrals in the stratosphere are vanishingly small, and it is apparent that the processes which convert the minor neutral species into the dominant ionic species must be very efficient. Information on the relative ion abundances, together with the rate constants for the production and loss of the solvated ion species, can be used to derive the concentrations of the minor neutral species in the stratosphere. Following the application of this technique to the derivation of nitric acid concentrations, as reported in the 1983-1984 *Report on Research* (AFGL-TR-85-0113, p.21), we have recently measured the rate constants for the reactions of water cluster ions, i.e., $H_3O^+(H_2O)_n$ for n = 1 to 11, with acetonitrile, a constituent of the predominant positive ion species in the stratosphere. We have used these data to derive the concentration of acetonitrile as a function of altitude. In the altitude range from 10 to 45 km, the mixing ratio of acetonitrile was found to vary from 1.5×10^{-11} to 1.5×10^{-13}. Because the temperature dependences of the rate constants for the solvation reactions were found to be significantly stronger than previously thought, the derived acetonitrile concentrations are as much as 40 per cent lower than had been estimated earlier.

Many exothermic reactions between neutral species are known to have large activation energies and thus to be fast at very high temperatures, e.g., in shock tubes, but to be very slow at room temperature. The rate constant at room temperature, which may be immeasurably small, can be estimated from the activation energy measured at the higher temperatures. A few examples have been known since 1980 in which a reaction similar to the slow neutral reaction occurs at room temperature with a large rate constant when one of the reactants is clustered to an alkali metal positive ion. An example is the reaction between ozone and nitric oxide, producing diatomic oxygen and nitrogen dioxide, a reaction which is about 10^4 times faster when the ozone is clustered to a lithium ion than when the lithium ion is absent. Several other such ion-assisted reactions have recently been identified using the SIFT apparatus. The most striking example is the reaction between nitrogen dioxide and carbon monoxide,

$$NO_2 + CO \rightarrow NO + CO_2.$$

The estimated rate constant for this reaction at room temperature, based upon its measured activation energy, is about 10^{-42} cm^3s^{-1}. When the nitrogen dioxide is clustered to a lithium ion, the reaction is

$$Li^+(NO_2) + CO \rightarrow NO + Li^+(CO_2).$$

The rate constant for this reaction measured using the SIFT is 7×10^{-12} cm^3s^{-1}, i.e., about 10^{30} times larger than that estimated for the similar neutral reaction in the absence of the lithium ion. When the nitrogen dioxide is clustered to a sodium ion, the rate enhancement factor is 10^{29}. Theoretical calculations have been performed in order to explain these observations. These calculations suggest that, in the presence of the alkali metal ion, the geometry of the reactant neutral is shifted toward that of the transition state in the similar neutral-neutral reaction in the absence of the ion, thereby lowering the activation energy of the reaction. The present studies involve only species in the gas phase. Nevertheless, these results on ion-assisted reactions have interesting implications for chemical catalysis and for reactions occurring on solid surfaces.

Many chemicals are known which react with free electrons in the gas phase to produce negative ions. Sulfur hexafluoride, SF_6, is a well-known example which has long been used in ionospheric chemical release experiments to reduce local electron densities and in high-voltage switch gear to prevent the occurrence of electric discharges. To be useful as an electron quenchant, the species must attach electrons rapidly and must generate negative ions which are stable in the local environment. A necessary but not sufficient condition for stability is that the energy required to detach the electron from the resulting negative ion must be large. A new class of useful electron-attaching molecules has recently been identified, following the realization that the dissociative electron attachment process is chemically equivalent to an acid-base reaction in which the attaching molecule is the acid and the electron is the base. On the basis of this model, the strongest acids should be among the best electron quenchants. Studies of the ion chemistry of these acids in the SIFT have shown that the electron detachment energies of the negative ions produced by electron attachment to strong and super acids are exceptionally large, e.g., about 5 eV for the fluorosulfonate anion produced from the super acid called fluorosulfonic acid, FSO_3H. (A super acid is an acid stronger than pure sulfuric acid.) These ions have been found to be stable even in the presence of such reactive species as atomic hydrogen and atomic oxygen. Measurements made elsewhere under contract have shown that the electron attachment rates for the strong and super acids are very large and are close to the theoretical limiting values, based upon the de Broglie wavelength of the electron. The studies in the SIFT have also led to the first ordering of intrinsic acid strengths for the strong and super acids. The significance of intrinsic acidity of chemistry is that acid strengths are now known for these species in the absence of solvation effects which can change the order of acid strengths in solution as the solvent is changed.

The present results on electron quenchants have been obtained following our earlier work on the species PO_3, reported in the 1983-1984 *Report on Research* (AFGL-TR-85-0113, pp. 21, 22), in which it was found that the ion PO_3^- is particularly stable. The species HPO_3, known as metaphosphoric acid, is a strong acid. On the basis of the results reported here, HPO_3 is expected to be a good electron quenchant. Unfortunately, metaphosphoric acid does not exist as a stable species at room temperature and is therefore not a good candidate. As a result of the present studies on other strong acids and on the super acids, several new candidate electron-quenchant species are now available for experiments in which it is desired to produce effective and long-lasting perturbations of the local ionospheric electron densities. It is interesting that these newly discovered quenchants, the strong acids, are the same kinds of species which are known to constitute the terminal negative ions in the stratosphere. The vanishingly small concentrations of these acids present as neutral molecules in the stratosphere rapidly attach any free electrons generated in this region, leading to formation of the predominant negative ion species and reducing the free electron concentrations to levels below those existing at any higher altitudes in the earth's atmosphere.

Space Shuttle Mass Spectroscopy: Many experiments on the early flights of the shuttle were devoted to exploring the nature of the environment around the shuttle. One reason for these experiments was to assess the suitability of the shuttle environment for further experimentation. As an example, very little was known about how degassing of shuttle surfaces and shuttle operations such as water dumps and thruster firings would affect the environment and the scientific experiments in the shuttle bay.

The Air Force Geophysics Laboratory contributed to this effort by flying a mass spectrometer on the fourth flight of the shuttle (STS-4) in the summer of 1982. The instrument measured the kinds and amounts of neutral and ionic gases in the payload bay. The shuttle environment was found to be considerably different from the natural atmosphere. A summary of early results can be found in the 1983 - 1984 AFGL *Report on Research* (AFGL-TR-85-0113, pp. 18-20).

Continuing analysis of the STS-4 data has provided additional information about the condition of the shuttle environment. As reported before, water vapor due to outgassing of shuttle surfaces is the most concentrated contaminant species. Because the mass spectrometer can detect both neutral gas molecules and ions, water concentrations can be measured in two ways. In the neutral mode, water molecules lead directly to a water signal. In addition, charge transfer reactions of neutral water with ambient oxygen ions produce water ions. These ions can be detected in the ion mode. Estimates of the water concentration made from both types of data show qualitatively the same behavior. Even though calculating an absolute concentration is difficult, the two types of data appear to bracket the actual concentration. An estimate of the lower limit for the water column density at the highest water signal intensities is 3×10^{13} cm^{-2}.

There is a strong correlation between the intensity of the water and the temperature of the instrument and the shuttle bay. Increased outgassing rates of water absorbed to shuttle surfaces is the most likely explanation. The water concentration was high at the beginning of the flight and dropped to near the instrument background by mid flight. This drop is attributed entirely to the corresponding drop in temperature.

Interestingly, water dumps appear to have essentially no effect on the water vapor measurements in the shuttle bay. This may be due to scattering of water off the payload bay doors, formation of ice crystals rather than vapor as the water leaves the dump port, or good collimation of the beam of water.

Small rocket engines called vernier thrusters are used during shuttle flights to change the attitude of the spacecraft. Large changes in the concentrations of gases in the payload bay due to these thruster firings were reported in the last *Report on Research* (AFGL-TR-85-0113, p. 19). Further analysis of these data has shown that there are large differences between the measured composition changes and the calculated composition of the thruster exhaust plumes. The differences are attributed to kinematic effects as the exhaust gases collide with other species in the environment. Generally, the lighter exhaust products such as hydrogen are more easily scattered into the instrument than the heavier gases, and are nearly always observed. In addition, species such as helium that are not produced by the engines but which are present in the environment can be scattered into the mass spectrometer as a result of collisions with the thruster exhaust gases.

The success of the STS-4 mass spectrometer experiment prompted a number of follow-on programs. The list of new programs includes: (1) a second flight of essentially the same instrument with the goal of again measuring the shuttle environment (AFP-675), (2) a materials evaluation experiment to be conducted jointly with NASA (EOIM-III), (3) an engineering prototype and science payload to be flown free of the shuttle to investigate interactions between the environment and spacecraft (IMPS-1), and (4) a free-flying satellite that will measure the effects of chemical releases in low earth orbit (CRRES). Unfortunately, the explosion of the shuttle Challenger in January, 1986, has delayed launching these new experiments. All four of these programs were originally scheduled for launch between 1986 and 1988. It now seems unlikely that any of them will be launched before 1989. Instrument preparation and experiment planning will continue in the interim period.

Stratospheric Positive Ion Composition: The ions in the stratosphere form a very weak plasma distinctly different from the D-region, where electrons begin to dominate the atmospheric electric processes. Even though the ion concentrations in the stratosphere are only 1 part in 10^{14} of the neutral concentration, the low recombination rate between positive and negative ions and the proton affinities governing ion-ion reactions result in a situation dominated by ion chemical reactions. The stratosphere thus provides a unique natural laboratory to study ion reactions not easily duplicated on the ground. The stratospheric ion-measurements program has yielded the first measurements of stratospheric ion composition in the United States. Two highly successful missions were conducted on June 13 and October 5, 1985, from Holloman AFB, N.M. Excellent data were obtained from both flights, which included seven hours of data collection in the altitude regime from 29 km to 38 km in June, using an 11.6 million cubic foot balloon, and eight hours between 27 km and 41 km in October, using a 15 million cubic foot balloon. The data were obtained with a quadrupole ion mass spectrometer pumped with an ultra high speed vacuum pump cooled by liquid helium. Because this quadrupole spectrometer was larger than any other yet flown for this purpose, data on positive ion mass distribution was accumulated for ions of up to 1000 atomic mass units (amu) and for ions present in concentrations of less than 0.1 ion per cubic centimeter. The ion distributions have both altitude and seasonal dependence, but a rough average distribution showed 0.1 per cent of the positive ions with masses greater than 550 amu, 1 percent with masses greater than 300 amu, and 10 percent with masses greater than 150 amu. The most prominent masses observed were the proton hydrate clusters at masses 37, 55, 73 and 91 amu (corresponding to clusters of 2, 3, 4, 5 water molecules, respectively), and also a series at 60, 78, and 96 amu. The high resolution of the instrument permitted measurements of the isotopes of the peaks from this latter series, which, in turn, allowed determination of the origin of these peaks to be traced to clusters of acetonitrile (CH_3CN – 41 amu) and water molecules (18 amu). Many minor peaks were also observed and are still under investigation.

Stratospheric Neutral Composition: Concern over potential contributions to the catalytic destruction of the ozone layer, due to gaseous emission from various Air Force operations, led to an in-situ sampling program conducted with 26 balloon flights into the stratosphere over the ten year period, 1975-1984. The program was described in detail in the 1979-1980 *Report on Research* (AFGL-TR-82-0132, pp. 16-17) and a summary of the chlorine measurements and their significance appears in the 1983-1984 *Report on Research*

(AFGL-TR-85-0113, pp. 17-18). Subsequent evaluation of the measurements of oxides of nitrogen indicated values higher than those generally obtained elsewhere, but in line with some more recent model predictions. Thus, because of higher background content, Air Force emissions of oxides of nitrogen would be expected to have relatively less effect on the stratosphere.

Stratospheric bromine is postulated to be an even more efficient catalyst than chlorine in the destruction of stratospheric ozone. Although bromine is present in the stratosphere at significantly lower concentrations than chlorine, it has been used in a fire suppressant on Air Force aircraft. During the balloon flights, inorganic bromine species were collected coincidently with sampling of the acidic and particulate chlorine species in the lower stratosphere. Bromine content was determined by neutron activation analysis. The results were in agreement with, and filled gaps in, earlier measurements by another group, thus indicating that stratospheric bromine has not increased, measurably, over the approximately seven years between the two sets of observations. In addition, the results were in agreement with one-dimensional photochemical model predictions.

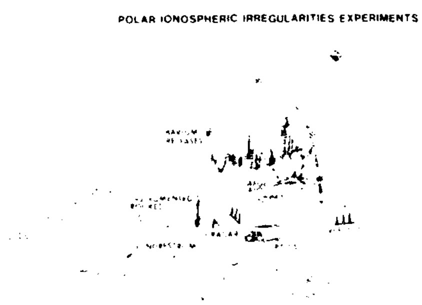
IONOSPHERIC EFFECTS

Large-scale ionospheric processes such as those which control the polar cap, the auroral oval, the F-layer trough, and the Appleton Anomaly structure the global ionosphere. This large-scale structuring results from the complex interactions of neutral winds and ionospheric plasma, plasma drifts driven by electric fields, ion chemistry, and particle precipitation. It affects Air Force systems operating in the rf range. Medium and small-scale processes lead to the formation of irregularities from tens of kilometers to centimeters in size, as observed, for example, in equatorial electron concentration depletions, in the high-latitude ionosphere, and in polar-cap F-layer auroras and patches. These medium and small-scale irregularities result from various plasma instabilities and on some occasions from localized strong particle precipitation as, for example, in discrete auroras. They affect radio propagation in the frequency range from hf through shf and are therefore of importance to Air Force systems from the high frequency Over-the-Horizon-B (OTH-B) Radar to the satellite communications systems (AFSATCOM, MILSATCOM) operating over the whole uhf and part of the shf band. The same physical processes are believed to drive similar effects through ehf frequencies in the nuclear-disturbed ionosphere.

Theoretical efforts during this reporting period have been concerned with studies of ionospheric scintillation generation, relating ultraviolet images to ionospheric densities for mapping the global ionosphere, and the modeling of large-scale ionospheric dynamics with special emphasis on the polar ionosphere.

Experimental efforts in the reporting period focused on: determining the transport of the polar ionosphere by using a multiplicity of airborne, ground-based, and satellite diagnostics; motion of the polar, auroral, and subauroral ionosphere by AFGL's Airborne Ionospheric Observatory (AIO), a modified NKC-135 aircraft, in support of OTH-B testing; investigation of polar F-layer irregularities, their generation, dynamics and decay; and experiments to artificially trace disturbances in the ionosphere.

Project PIIE: A coordinated rocket, radar, ground and aircraft experiment, Project PIIE (Polar Ionospheric Irregularities Experiment) was conducted in March, 1985, from Sondrestrom AB, Greenland. The objectives were to measure the detailed plasma and field parameters associated with a polar cap F-layer aurora, and to define processes which lead to the generation of ionospheric irregularities within this type of aurora. The irregularities cause severe amplitude and phase fluctuations (scintillation) on Command, Control, and Communication satellite systems.



Schematic Illustrating the Various Diagnostics and Rocket Experiments Involved in the Polar Ionospheric Irregularities Experiment (PIIE).

An All Sky Imaging Photometer installed in the AFGL Airborne Ionospheric Observatory was used in real-time to locate a subvisual arc within the nominal rocket trajectory. When a suitable arc was detected, the launch command was relayed to the ground Launch Control. The rocket payload successfully crossed through the polar cap arc and all instruments performed as planned. Intense fluxes of low energy (less than 200 eV) electrons defined the region of particle precipitation (see the figure).

Electron density and temperature and ion composition measurements characterized the study of the plasma environment within the arc. These measurements were critical to verifying a numerical auroral simulation code being developed to model ionospheric response to particle fluxes.

Ion density fluctuations were confined to the vicinity of the arc and confirm irregularity generation in this area. Analyses of these data are continuing to identify plasma instability mechanisms responsible for irregularity generation.

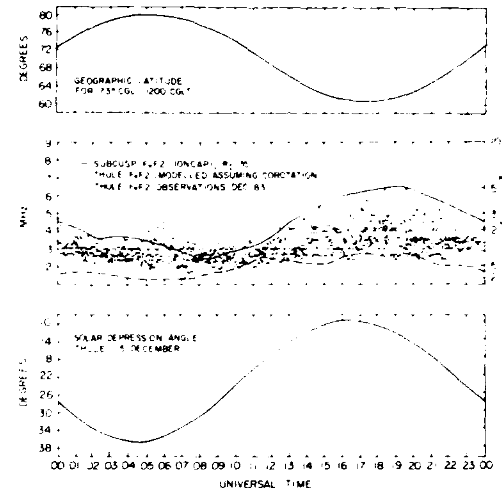
The electric field instrument provided the first three component electric field measurements within a polar cap aurora. These have been used in a model calculation to compute the electric circuit parameters associated with the arc.

Field-aligned currents computed from the electric field measurements show excellent agreement with those estimated from the particle fluxes. The combined measurements confirm that polar cap arcs are the optical signatures of plasma flow reversals and field-aligned currents flowing in the polar cap ionosphere. The large spatial coverage afforded by optical imaging will provide an improved specification of two dimensional flow in the polar cap during IMF northward conditions.

To quantitatively study the source region for ionization within "patches", a theoretical high latitude/polar cap ionospheric F-region model, recently developed at AFGL, was used to calculate electron density profiles as a function of latitude and local time. Physical processes included in the model are ionization production by solar ultraviolet radiation and energetic electron precipitation, loss through charge exchange with N_2 and O_2, and transport by diffusion, neutral wind, and horizontal $E \times B$ convection. Under conditions appropriate for patch formation, the ionization passing over Thule between 1200 and 2000 CGLT was found to be produced by solar extreme ultraviolet radiation south of the cusp and an additional ionization component due to the particle precipitation in the cusp. A comparison between calculated and observed f_oF_2 values at Thule at 1400 CGLT showed excellent agreement. The theoretical model allows us to conclude that solar-produced ionization accounted for two-thirds of the total peak electron density, while production by energetic particle precipitation accounted for one-third.

Polar Cap Plasma Characteristics: Of special significance to Air Force systems is an ongoing study which investigates the structure and dynamic processes in the polar cap ionosphere with emphasis on determining the source region of polar cap plasma, and irregularity generation and transport. The severity of outages in Command, Control, and Communication systems due to polar-cap ionospheric irregularities is also being assessed. The AFGL Airborne Ionospheric Observatory (AIO) is flown to specific magnetic latitude/local time locations to perform radio wave and optical sensing of ionospheric parameters. These measurements are coordinated with observations using the Sondrestrom Incoherent Scatter Radar and a number of satellites: HILAT, Dynamics Explorer, VIKING, DMSP, AFSATCOM and GPS. Extended periods of ground-based observations by the AIO instrumentation provide a supporting multidiscipline database. The unified description of polar cap F-layer structure previously discovered using the AFGL AIO has been further confirmed and refined.

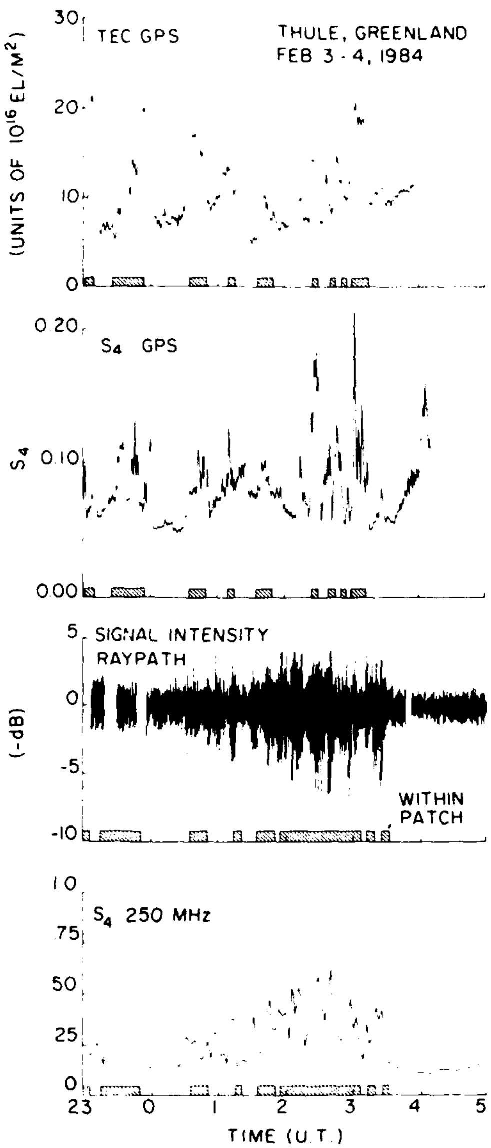
An investigation of the polar cap ionosphere near the peak of the last solar cycle identified polar cap F-layer arcs and



Geographic Latitude of Point on the CG Noon Meridian Just South of the Cusp as a Function of UT (Top). Composite of All f_oF_2 Measurements Made between December 4 and 10, 1983. (Center). (Solid curve shows UT variation of f_oF_2 in candidate source region south of the cusp, as predicted from IONCAP median model, for R_1 = 35, December. Broken curve shows f_oF_2 from model computation of local production, solar EUV and particles, with corotation assumed.) Solar Depression Angle for Thule, December 15. (Bottom)

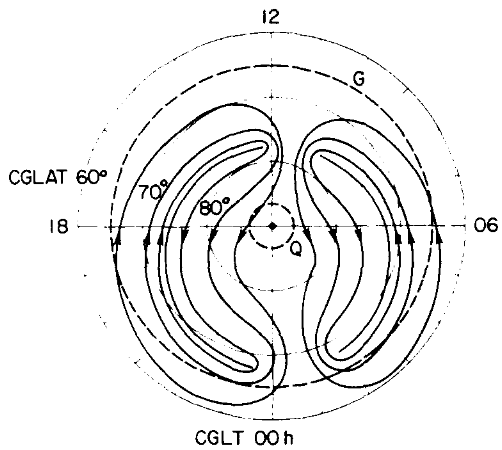
ionization patches as unique features of the polar cap ionosphere, and as sources of severe scintillations observed on 250-MHz satellite beacon signals. The continuing investigations in January and December 1983, and January, 1984, have shown that arcs and patches persist as the dominant features of the winter polar-cap ionosphere during periods of low sunspot numbers. Improved ionospheric soundings made at Thule, Greenland (86° CGL), starting in November, 1985, showed a clear diurnal variation for the occurrence of the patch-type ionization. Discussion of various possible mechanisms producing the observed ionization patches leads to the conclusion that the solar-produced ionosphere equatorward of the dayside cusp is the source region of the ionization patches (see the figure). Polar plasma convection transports this ionization across the cusp and the central polar cap. The local time dependence of the occurrence of the patches at Thule is shown to be a manifestation of the well-known universal time control of the polar cap F-region. Recent analysis has shown a strong positive solar-cycle dependence of the scintillations measured during three extended campaigns. The diurnal variation of scintillations is almost flat at solar maximum and has a local time variation very similar to that of the patch type ionization at solar minimum. Both arcs and patches contribute to substantial scintillations around solar maximum, while only the patches are responsible for the considerably weaker scintillations during solar minimum.

Coordinated measurements of F-region plasma patches were conducted on February 3-4, 1984, from Thule and Sondrestromfjord, Greenland. Optical, ionosonde, amplitude scintillation, total electron content (TEC), and incoherent scatter radar measurements were combined to reveal several new aspects of the structure and transport of these localized regions of enhanced F-region ionization shown in the figure. For the first time, these patches were directly tracked flowing in the antisunward direction over distances of 3000 km from the center of the polar cap to the poleward edge of the auroral oval. Quantitative measurements of TEC show increases of 10-15 TEC units within the patches, above a background polar cap value of 5 TEC units. Amplitude scintillation measurements show the presence of ionospheric irregularities through the entire patch, with a weak indication of stron-



Composite Plot of: (a) Total Electron Content, (b) S 4 Index for the GPS Satellite, (c) 250 MHZ Signal Strength, and (d) S_4 Index for the Polar Beacon Satellite, for the Period 2300 UT, February 3, to 0500 UT, February 4, 1984.

ger scintillation on the trailing (or E × B unstable) edge.



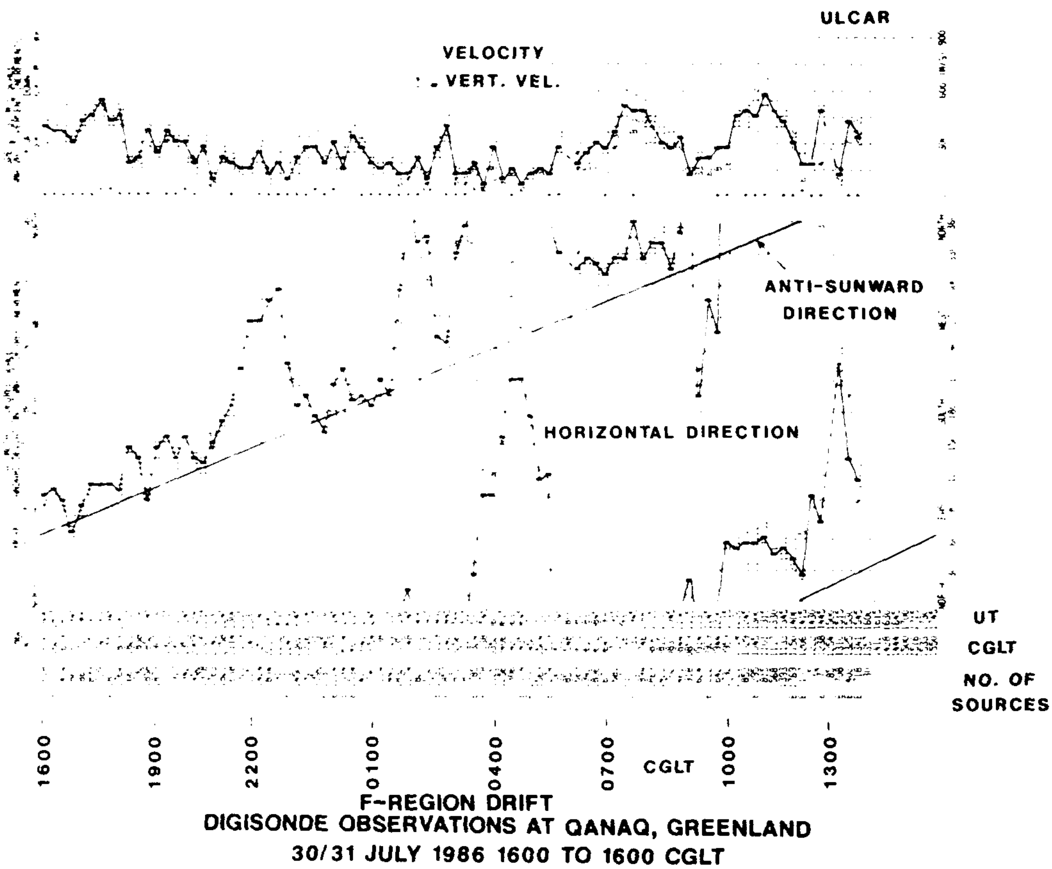
Schematic Diagram of Polar Two-Cell Convection Pattern in Corrected Geomagnetic Latitude/Local Time Coordinates. (The locations of the drift-measuring stations, Goose Bay (G) and Qanaq (Q), are indicated by dashed circles. The drift direction at Goose Bay switches from westerly to easterly around midnight, while Qanaq observes a clockwise rotation in 24 hours.)

Polar Plasma Convection: Satellite and incoherent scatter radar (ISR) observations have shown the existence of a large ionospheric plasma-convection system which affects the high-latitude ionospheric region down to 50° corrected geomagnetic latitude (CGL). This convection occurs generally in the form of a two-cell pattern (see the figure) with plasma flowing antisunward over the central polar cap and returning in the sunward direction along the evening and morning flanks of the auroral oval. The source of this plasma convection is a polar-cap electric potential generated by the interaction of the solar wind with the magnetosphere. The polar-cap convection is of high importance to the maintenance of the polar-cap ionization (see the earlier discussion of polar-cap patches and their UT dependence) and the generation of the midlatitude trough. The convection is also important to the generation, transformation, and distribution of small-scale irregularities responsible for scintillations and radar clutter, which are detrimental to the operation of radio frequency dependent systems operated at mid to high latitudes by the Air Force.

The development of models of the distribution of ionization and irregularities requires a systematic database of polar plasma convection and its dependence on solar/geophysical parameters, and its relation to resulting ionospheric phenomena. Since satellite measurements provide only snapshots along the satellite orbit, and incoherent scatter radar observations are costly and limited to very few locations, a new technique has been developed by AFGL and the University of Lowell to produce continuous convection data using a modern digital ionosonde, Digisonde 256.

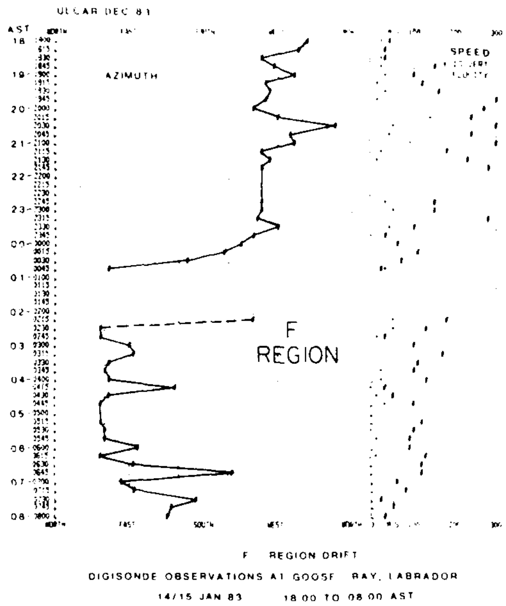
The technique is based on the reception of ionospherically reflected pulse transmissions with a spaced seven-antenna array. The complex spectra of the reflected signals, measured independently on each of the seven antennas, allow the determination of the reflection locations of energy in each spectral (Doppler) line. The resulting sky map gives reflection locations with the respective Doppler information. By a least-squares fit, a matching squares velocity vector is determined.

A systematic measurement program, conducted on the three Regular World Days of each month, was initiated at Goose Bay, Labrador (65° CGL) in January, 1985, and at Qanaq, Greenland (86° CGL), and Argentia, Newfoundland (58°



F-Region Drift Observed at Qanaq, Greenland, on July 30-31, 1986. (The straight lines indicate the antisunward direction. Large deviations are often associated with observations of polar cap F-layer arc transitions.)

(CGL), in November, 1986. The data in the next two figures show representative samples for the clockwise rotation of the drift vector as seen at Qanaq, and the 180° direction reversal routinely observed at Goose Bay. These observations correspond to direction changes to be expected from the simple model shown in the previous figure (dashed circles marked Q for Qanaq and G for Goose Bay). This new, low-cost technique will provide, for selected periods, continuously vital information on the large-scale plasma transport at high latitudes. Of major importance to the automation of the drift data acquisition is the ARTIST program (Automatic Real Time Ionogram Scaler with True height analysis) developed by the University of Lowell in close cooperation with the Ionospheric Effects Branch. The automatically identified trace of the overhead ionogram is used to guide frequency- and height-gate selection for the automatic drift measurements. This approach has been working successfully at Qanaq and Argentia since November, 1986.



F-Region drift observed at Goose Bay on January 14-15, 1983, shows switch from westerly to easterly drift near midnight.

Auroral Proton Precipitation: Although the predominant source of ionization in the continuous (diffuse) aurora on a global basis is the energetic (primary) precipitating electrons, it is now well-documented that the precipitating protons (and H atoms) can occasionally produce ionization comparable to, or greater than, that produced by the electrons. A recent study of the nearly coincident Chatanika radar electron density measurements and NOAA-6 particle data revealed that within a wide latitudinal range between 64° and 67° invariant, a continuous (diffuse) auroral E-layer with a peak electron density of 1-2 $\times$ 10^5 cm^{-3} was produced entirely by proton precipitation.

Several years ago, the Ionospheric Physics Division developed a transport-theoretic method which leads to exact solutions for the precipitating proton and H atom fluxes and the energy deposition rate when the incident proton flux is given. Recently, this transport-theoretic proton precipitation code was upgraded to include calculations of the electron density profile and the energy deposition function, which is often useful in performing direct calculations of the energy deposition rate and the ionization rate. The transport-theoretic code was used to analyze the nearly coincident Chatanika radar data and NOAA-6 particle data, and excellent agreement between the theoretical results and the radar data for the shape of the electron density profile and for the location of its peak was obtained. To the best of our knowledge, this is the first definitive comparison between theory and experiment for a pure proton aurora. The radar data and the transport-theoretic results were also compared with the results obtained using the semi-empirical continuous slowing down method of Rees. The transport-theoretic method was found to be a more complete, and relatively more accurate, description of the proton-H atom precipitation than the method of Rees. The exact transport-theoretic energy deposition function, when compared with the one constructed and used by Rees, explains why the Rees method does not produce the observed electron density profiles.

Solutions of the Plasma Kinetic Equation With Collisions: In laboratory and space plasmas, discrete particle interactions (collisions) often play a significant role in determining the characteristics of the plasma waves. Finding an exact solution of the linearized plasma kinetic equation when collisions are included is a formidable task. Over the years, studies of collisional effects have employed methods of solution tailored to a specific model of the collision operator. Recently, scientists in the Ionospheric Physics Division gave an expansion method which can be used to derive the collisional plasma dielectric *function for any given collision* operator. Application of this method to solve the Balescu-Lenard-Poisson equation produced a closed-form expression for the collisional dielectric function to the first order in the pertinent collisionality parameter, where all types of collisions (*electron-electron, electron-ion, ion-electron*, and ion-ion) in a fully ionized plasma were included. With this dielectric function, several aspects of the collisional effects were studied.

Solving the dispersion relation for high-frequency Langmuir waves in the long wavelength limit, we obtained an expression for the collisional correction to the well-known Landau formula. A laboratory experiment to check this result is currently in progress.

A closed-form expression for the electron density fluctuation spectrum in a weakly-collisional electron-ion plasma in thermodynamic equilibrium was derived. Comparing the collisionless and the collisional results for the fluctuation spectra, we found that the electron-ion collisions are the dominant collisions and that they enhance density fluctuations near zero frequency and near the ion-acoustic frequency. A confirmation of this newly predicted collisional enhancement of the density fluctuations near the ion-acoustic frequency may come from a suitably designed incoherent radar scatter measurement of ionospheric electron density fluctuations.

Solving the dispersion relation for ion-acoustic waves, we found that the electron-ion collisions have a destabilizing effect on the ion-acoustic waves. This explains the previously mentioned enhancement of the density fluctuations near the ion-acoustic frequency. A more exciting new result is that, when $T_e >> T_i$, the destabilizing effect of electron-ion collisions *can overcome the damping effects*, including Landau damping and ion-ion collisional damping, and drive the ion-acoustic wave instability. This instability, which can be excited without the presence of any current, will provide a much more efficient mechanism for energy transfer between electrons and ions than the purely collisional relaxation mechanism. If there is a current, the destabilizing effect of electron-ion collisions will have an impact on the estimate of the amount of current necessary for the ion-acoustic instability in a weekly-collisional plasma such as the ionospheric F-layer plasma.

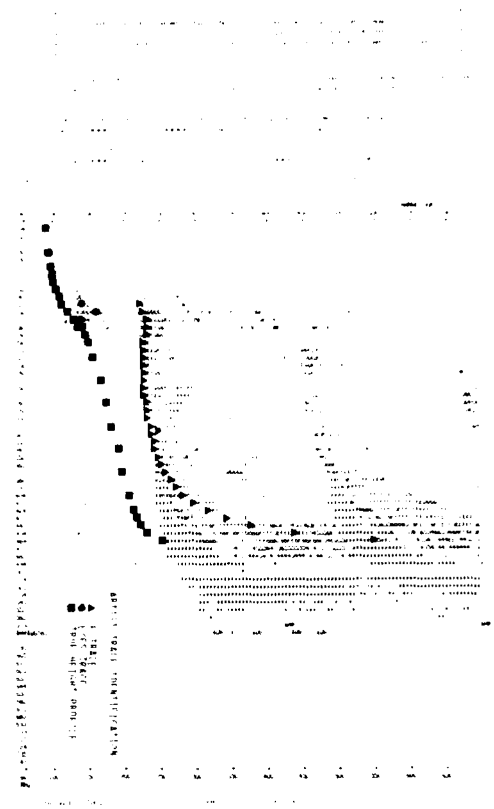
AWS and OTH-B Support: Real-time acquisition of ionospheric data, generally a costly requirement, has been made cost-efficient through the development of digital ionospheric sounders supported by AFGL and a computer-based Automatic Real Time Ionogram Scaler with True height analysis (ARTIST) program. Testing of the quality of the trace identification using 375 half-hourly ionograms from Argentia, Newfoundland, has shown that more than 90 percent of the automatically identified traces are acceptable, which is an excellent result in view of the proximity of the station to the disturbed polar ionosphere. The Air Weather Service, with AFGL support, is currently procuring twenty Digital Ionospheric Sounding Systems (DISS), which implement these techniques, for deployment in an almost global AWS-DISS net.

As a precursor to this deployment, AFGL has facilitated the installation of an ionosonde at Argentia, Newfoundland, where it is operating under the remote control of personnel at the AFGL Goose

Bay Ionospheric Observatory. The Argentia and Goose Bay ionosondes are essential ionospheric sounding data sources for the testing, as well as the day-to-day operation, of the Over-the-Horizon Backscatter Radar (East Coast Radar System), which is currently being deployed in Maine. To speed up access to the sounding data, a dial-up capability has been activated, which permits real-time remote data acquisition from the Goose Bay and Argentia ionosondes by the AWS operators at the OTH-B radar, and by AFGL. This makes it possible to assist AWS in the interpretation of difficult situations.

The figure is an example of a digital ionogram received at AFGL via telephone dial-up of the Argentia ARTIST. The ionogram shows the o-component with 6-level amplitude resolution (letters indicate positive, numbers negative, Doppler), the x-component (identified by x only), and oblique echoes (identified by a dot). The automatically identified F-layer o-echoes are marked by a = sign. The ARTIST software also converts the ionogram into a true-height electron density profile, which is shown by the & symbol.

The availability of real-time ionospheric data has resulted in a significant improvement in short-term ionospheric prediction. Rapid changes in f_oF_2, the plasma frequency at the maximum of the F-layer, greater than 20 percent per hour are routinely observed during a 3-4 hour period around F-region sunrise and for a 2-3 hour period around F-region sunset, independent of the phase of solar activity cycle. These rapid changes in f_oF_2 are usually larger around sunrise hours than those around sunset hours. During the solar maximum, hourly changes as high as 50 percent around sunrise and 30 percent around sunset have been observed.



Digital Ionogram Obtained by Telephone Dial-up Service from Argentia, Newfoundland.

These rapid changes require improved short-term f_oF_2 predictions for the frequency management of the OTH-B radars. The scheme using real-time hourly ionospheric soundings and an extrapolation of the prior four day average hourly slope was found to be satisfactory for the sunrise predictions of f_oF_2.

Initially, the scheme was tested using a small database of four months representing four seasons, high and low solar activity periods, and restricted only to sunrise hours. The scheme has been expanded to include all 24 hours, all four seasons (the whole year's, high (1969) and low (1976) solar activity), using an extensive database from the high-latitude ionospheric stations at St. Johns, Ottawa, and Winnipeg. The scheme works satisfactorily for all conditions. The analysis shows that the scheme reduces the errors in f_oF_2 predictions by 40 percent over those from the IONCAP model during the transition periods of sunrise and sunset involving rapid changes in f_oF_2 lasting over the periods of 3-4 hours.

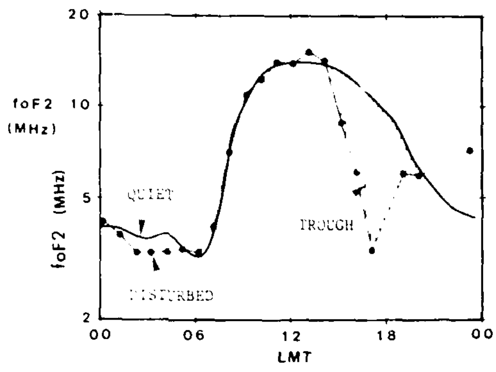
F-Layer Trough: The daytime F-layer at high latitudes is found to undergo extreme depletions in electron density as a result of the ionospheric trough. The trough, which is produced by the convection of ionospheric plasma driven by magnetospheric electric fields, is visible in routine vertical ionospheric soundings of f_oF_2. Although not previously recognized, signatures of the trough are rapid depletions of electron density by factors of 2 to 10. These depletions occur in the diurnal distributions measured by ground stations as they pass beneath a convection pattern which moves through the latitude of the station with local time.

The effect of the trough is seen in the daytime F-layer at Uppsala, Sweden (56.5° magnetic latitude (MLAT)), as the shaded "bite-out" which occurs on a disturbed day (average Kp = 5) as compared to a quiet day (average Kp = 0) in the figure. The onset of this bite-out corresponds to the passage of the station under the equatorward edge of the afternoon trough.

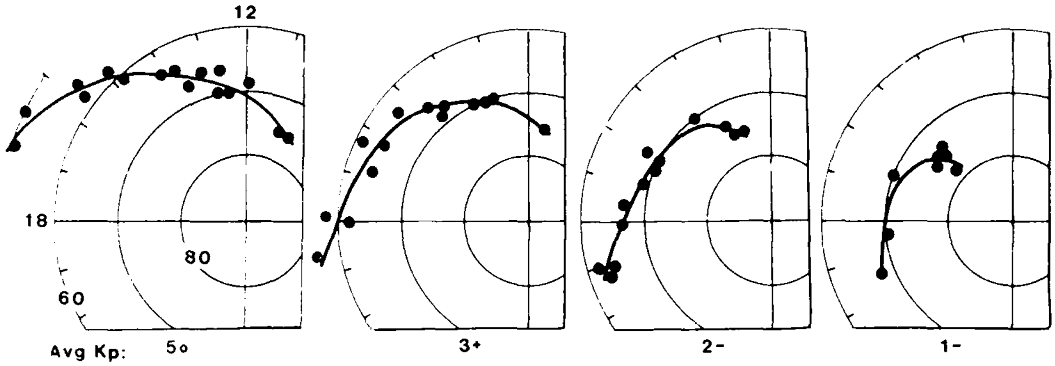
Investigation of the trough on a global scale appropriate to its extent requires a global array of ionospheric observatories. Since no such array exists today, the investigator has had to resort to archived data and has selected the most complete and extensive data base available, that acquired during the IGY. During this period, forty-four ionospheric sounding stations were operating at latitudes above 50° MLAT in the northern hemisphere. Recordings were simultaneously made at every UT hour and at 15 minute intervals on world days. The month of December, 1958 (winter solstice and solar maximum), has been the most thoroughly studied to date.

These archived measurements, when examined using modern insights and coordinates of magnetic latitude, longitude (MLONG), and local time (MLT), yield a description of the trough for the first time as an integral, spatially and temporally continuous entity in its entire extent and UT duration.

The afternoon trough, as characterized by its equatorward edge, is detected on each of the 31 days of this study. It is found to be dependent principally on magnetic activity (Kp) averaged over the period of a day. It is stable in MLAT/MLT for as long as 17 hours UT and shows little dependence on changes in Kp which take



Ionospheric Soundings from Uppsala, Sweden, for 2 Days Showing that, in Comparison to the Quiet Day, the Disturbed Day Undergoes a Depletion (shown shaded) as a Result of the Daytime Trough.



Equatorward Boundary of the Daytime Trough for 4 Days Showing that the Boundary Rotates to Earlier MLT and Expands to Lower MLAT as Average Kp Increases.

place during such periods. On the most disturbed day, the trough is its most extensive; the trough boundary extends in MLAT/MLT from 75°/1030 to 51°/1630 and is nearly stationary in these coordinates for a duration of 14.5 hours UT as observed by 16 stations spanning 220° MLONG. The figure shows this most disturbed day (on the left) together with three other days, the average Kp of which decreases from left to right. Note that as average Kp increases from quiet to disturbed (to the right), the trough rotates to earlier MLT (by 5.5 hours) and expands to lower latitudes (by 20° MLAT).

Rotation to earlier MLT as a consequence of increased activity has been indicated by a number of studies of the convection pattern. In addition, the trough boundaries in the figure tend to reverse direction with respect to the noon-midnight meridian between lowest latitude near dusk and highest latitude near midday. In this respect, they resemble convection contours which reverse from sunward to anti-sunward within this range. The trough in the daytime has been observed by incoherent scatter radar to lie within a region where convection velocities are greater than 1 km per second. Accordingly, the trough boundaries shown in the figure are apparently the loci of convection contours of this high velocity.

Pronounced longitudinal differences occur in the daytime trough in that the afternoon trough predominates in eastern MLONG but the morning trough predominates in western MLONG. In addition, near midnight large longitudinal differences occur in f_0F_2 particularly during quiet times. These phenomena are under investigation because they create large differences in propagation conditions for OTH-B radars which will operate in these two sectors.

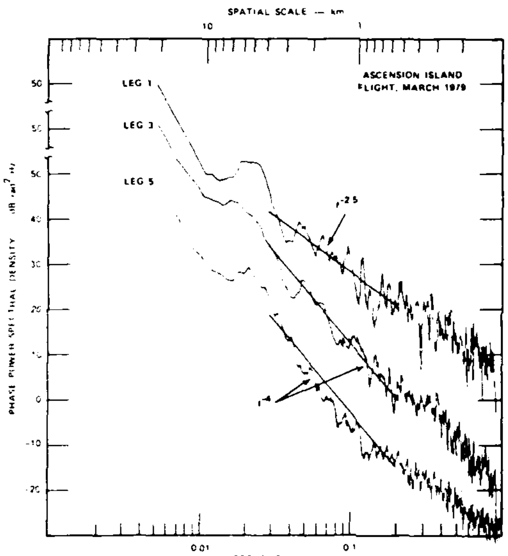
Because the archived database spans nearly five decades, the technique of trough investigation described here promises to provide results not only on the longitudinal effects, but also on seasonal, hemispheric, and solar cycle dependence as well.

Theoretical Modeling of the Ionospheric F Region: At low latitudes near the magnetic equator, vertical E $\times$ B drift is the primary mechanism for transporting plasma in a direction perpendicular to magnetic field lines. During daytime hours, upward E x B drift is responsible for creating crests in ionization on either side of the magnetic equator at ±15° to 18° dip latitude, producing the so-called "equatorial anomaly." Recent measurements of 6300 Å airglow intensity and meridional neutral winds by a Fabry-Perot interferometer at Arequipa, Peru (16°S, 71°W geographic, 3.2°S dip latitude), however, indicate that at night, neutral winds may significantly affect vertical plasma transport even down to 5° dip latitude. The observations revealed widespread areas of airglow depletions with reductions in intensity by factors as large as 3 or 4. These reductions correlated well with large increases in the equatorward (northward) wind. On occasion, the usually small meridional wind reached a velocity of 100 m per second near 2200 LT, lasting 1 to 2 hours. Comparison with modeling calculations shows that the reductions in airglow intensity result from an upward movement of the ionosphere along the inclined magnetic field lines driven by the equatorward neutral wind. The agreement with observations is excellent, and demonstrates that care must be taken in assuming that vertical E × B drift is the only transport process capable of lifting or lowering the equatorial F-layer.

In another low-latitude study, a unique method for inferring equatorial field-line-integrated electron density volumes was demonstrated using observed whistler dispersion values. A rocket launched from Punto Lobos, near Lima, Peru, on March 21, 1983, observed lightning-induced whistler trains on both the upleg and downleg of the flight. Model calculations of the expected whistler dispersions were compared with the observed values and from this comparison, fairly accurate estimates of the bottomside F1 molecular ion densities could be obtained. The density values were too low to be observed by ground-based coherent scatter radars but were highly variable. This "remote-sounding" technique was used to measure F1 region densities just after sunset near the equator. These densities may vary between 1×10^3 and 2×10^4 el/cm^3 and are extremely important in determining whether equatorial plasma instabilities will or will not occur.

A semi-empirical low-latitude ionospheric model (SLIM) has been developed jointly at AFGL and Boston University which produces F-region electron density profiles more quickly and more realistically than presently available empirical models. SLIM is generated by first solving the time-dependent plasma continuity equation numerically, which produces electron densities from 180 to 2000 km, every 2° dip latitude (24°N to 24°S dip latitude) and every half-hour local time (over the 24 hour day). A set of six coefficients at each latitude/local time position is then found which reproduces the theoretically calculated profiles. The coefficients themselves comprise SLIM and are used to quickly regenerate electron density profiles. Nine SLIM cases have been produced covering three seasons (equinox, June solstice, and December solstice) for each of three solar-cycle activity periods: low, moderate and high, corresponding, respectively, to F1 0.7 cm values of 70, 125, and 180. In addition to electron density profiles, SLIM also provides total electron content values and 6300 Å nighttime airglow intensities as a function of latitude and local time. The model is being merged with the Air Force Ionospheric Conductivity and Electron Density (ICED) model, which is presently operational at Air Weather Service.

Evolution of Equatorial Plasma Depletions: The continuing investigations into the origin and lifecycle of equatorial plasma depletions has led to the re-inspection of a unique data set collected by the AFGL Airborne Ionospheric Observatory flying in the South Atlantic. In March, 1979, the aircraft conducted this unique experiment to measure the plasma characteristics within an eastward drifting and decaying plasma depletion. The All Sky Imaging Photometer was used to locate depletion and to direct the aircraft through a series of east-west cuts through this feature as the entire ionosphere drifted eastward.



Phase Power Spectra for the Bubble over Successive East-west Cuts Labeled Legs 1, 3, and 5.

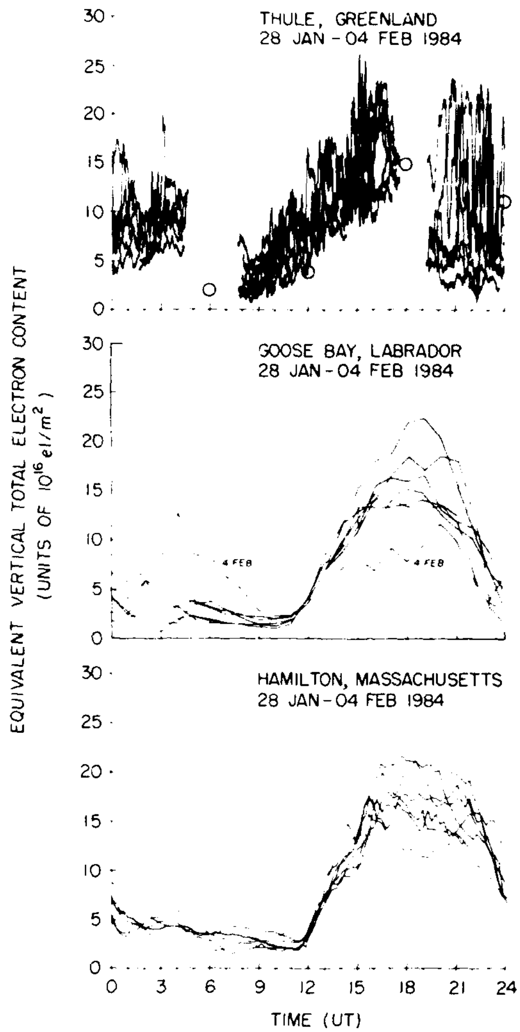
Complex signal scintillation observations of this isolated and decaying equatorial plasma bubble show evolution of irregularity energy over a broad range of scale sizes (see the figure). At wavelengths larger than about 4 km, the energy remains nearly constant with time. At shorter scale sizes, the spectrum maintains an approximate power law form (f^{-n}) and n increases with time. This behavior suggests that the effective cross-field diffusion rate in the F-region depends on scale size. Such a dependence has recently been predicted theoretically and is the result of magnetic field-line coupling to the E-layer.

This experiment represents the first successful measurement of the temporal evolution of small-scale irregularities in the disturbed equatorial ionosphere. Results provide needed input to theoretical models which attempt to describe this behavior.

Equatorial Ionospheric Irregularities: Measurements of the height distribution of irregularities of a few meters' scale size have been made over the magnetic equator by the high-power radars at Kwajalein Island and Jicamarca, Peru, by receiving the coherently returned back-scatter power from irregularities viewed in a direction perpendicular to the earth's magnetic field. These measurements have provided the ionospheric community with the bulk of the available evidence on the temporal distribution of the height of irregularities in the equatorial plumes. However, irregularities of only a few meters' scale size have been shown to decay much faster than those of approximately 1 km, which are responsible for amplitude scintillation observed in the 100-2000 MHz frequency range from transmissions from geostationary satellites.

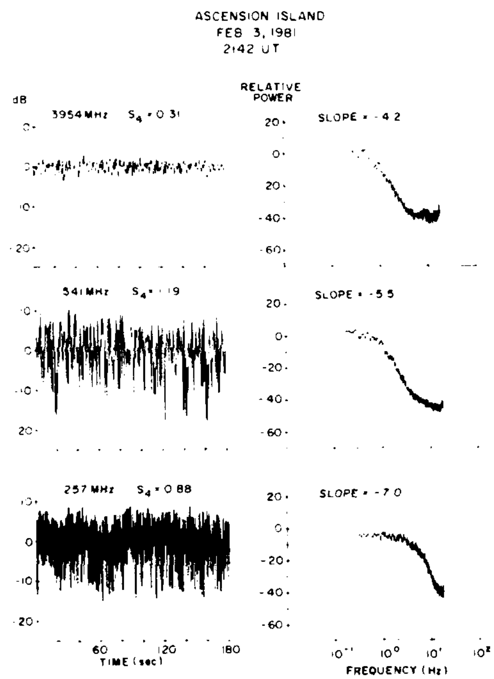
At a solar-terrestrial workshop held in New Delhi, India, in 1986, AFGL proposed that a satellite beacon ground receiving station network located in India be used to determine the height-time dependence of kilometer-scale irregularities and wind shear at different ionospheric heights over the magnetic equator on a continuous basis. Latitudinal gradients of total electron content (TEC) can also be measured by this chain of monitoring stations. The gradients in TEC can be used to improve high-frequency communication predictions as well as to provide important insight into possible mechanisms responsible for the generation of equatorial irregularities.

Polar Cap Total Electron Content: Measurements of TEC in the polar cap from Thule, Greenland, have shown that absolute values of TEC, obtained during the winter, when direct solar extreme ultraviolet radiation is minimal in the polar cap, are greater than those obtained from Goose Bay, Labrador, and from Hamilton, Massachusetts, during the same period. Overplots of diurnal values of TEC from Thule, Goose Bay, and Hamilton for an eight day period in January-February, 1984, are shown in the figure. Note that the maximum TEC values reached from Thule exceeded those from either Hamilton or Goose Bay. Not only are the absolute TEC values higher in the dark Thule ionosphere than in the sunlit mid-latitudes, but the variability is much higher.



Measurements of Total Electron Content at Thule, Labrador, and H. milton, Massachusetts.

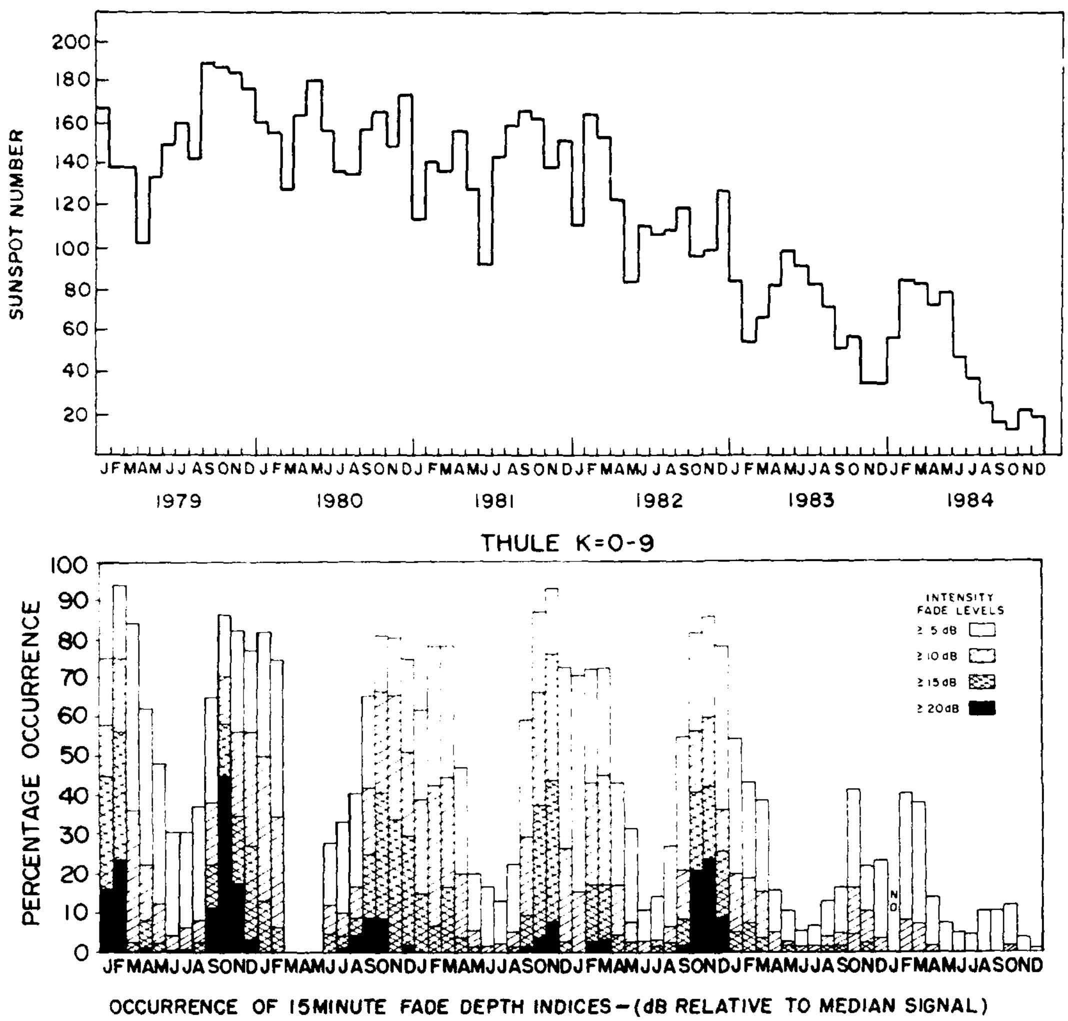
AFGL scientists suggested in 1985 that plasma is convected over the polar cap, by means of the large-scale electric field structure in the high-latitude ionosphere, from the mid-latitude afternoon sector where the plasma was originally generated by solar extreme ultraviolet radiation. Since that suggestion was made, a theoretical model of high-latitude F-region electron density was developed in 1986 which includes the effects of the solar extreme ultraviolet radiation, particle precipitation, and the earth's corotation. It was recently modified to include the contribution of plasma convected into the polar cap ionosphere from the afternoon cusp region. The TEC values obtained from this model are represented by the open circles in the Thule portion of the figure and can be seen to approximate fairly well the actual TEC observations during the magnetically disturbed days of this observation period. Because of the complexity of the model and the necessity to follow ionization produced elsewhere, which is then convected over the polar cap, the model has been run for only a few representative hours for comparison with Thule TEC data. However, the theoretical results do confirm that the inclusion of lower latitude ionization convected over the polar cap can produce a significant increase above the quiet-day TEC in the polar cap and can yield values comparable with those high TEC values actually observed from Thule.



Three-minute Data Segment of Scintillations Observed at 3954, 1541, and 257 MHz at Ascension Island and Their Respective Spectra.

Global Ionospheric Scintillation: Ionospheric scintillation effects encountered in the crest of the equatorial anomaly, polar cap, and auroral regions have been studied to provide information for the design and evaluation of the performance of multifrequency satellite communication links in these regions. The strength of the ionospheric irregularities and their motion control the scintillation structure, which needs to be defined for a successful system design. AFGL observations indicate that the scintillation effects are most severe in the equatorial anomaly region where, during sunspot maximum periods, the amplitude scintillations of satellite communication links at 1.5 GHz have often been observed to exceed the 30 dB dynamic range of the receiver. The magnitude of severe scintillations and their spectra defining the scintillation structures at 250 MHz, 1.5 GHz and 4 GHz obtained in the anomaly region are illustrated in the figure. Detailed statistics of phase scintillations and phase rates for this region were compiled for the first time in 1985-86. The phase and amplitude scintillation effects on AFSATCOM transmissions at 250 MHz have been recorded in the polar cap and auroral regions. Information regarding the magnitude and the structure of phase and amplitude scintillations in the polar cap and auroral oval has been compiled. During severe disturbances, amplitude scintillations exceeding 20 dB and phase deviations exceeding 12 radians at 250 MHz are encountered in the polar cap and auroral regions. The temporal structure of scintillations, which dictates the coherent integration time of space-based radar systems, is found to be governed primarily by the strength of the irregularities in the equatorial region, whereas at high latitudes the extreme variability of the irregularity movement is the major factor.

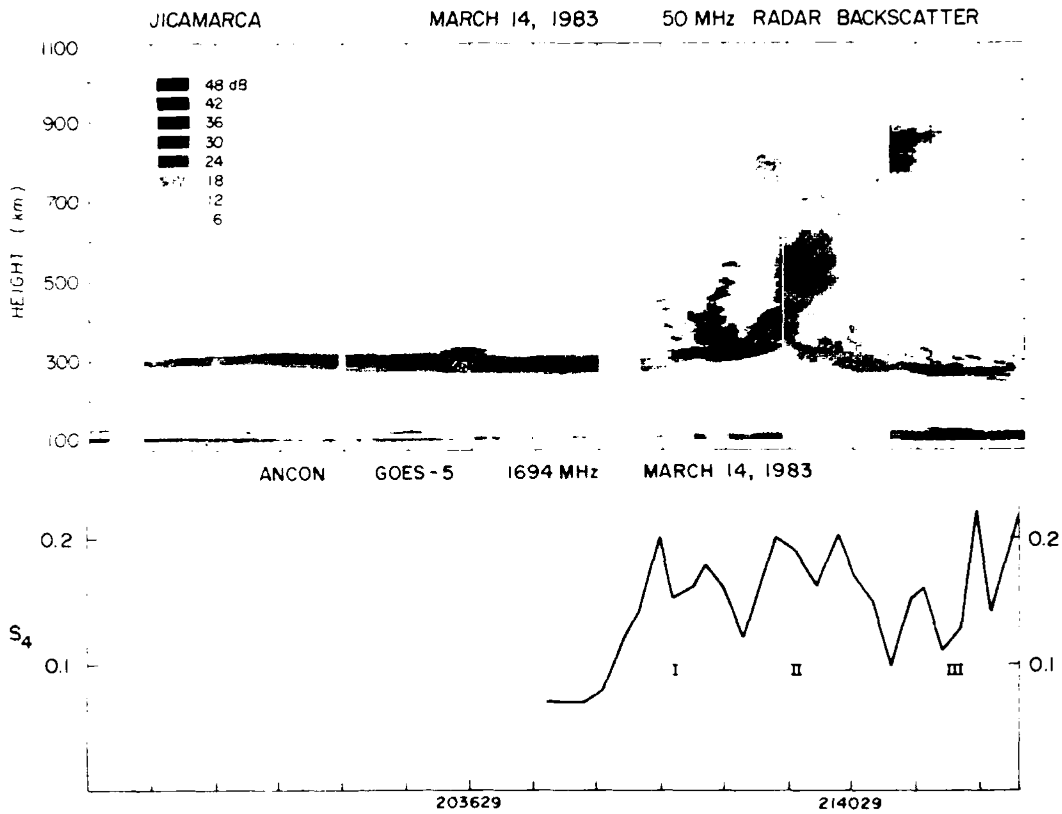
The long-term morphology (1979-1984) of intensity scintillations at 250 MHz in



Thule Intensity Scintillation Statistics at 250 MHz during 1979-1984.

the polar cap shows that in addition to the absence of diurnal variation of scintillations, and the presence of an annual variation with a pronounced minimum during local summer, a marked solar control of scintillation activity exists. Scintillations are found to decrease abruptly when the solar activity falls below a threshold level, as shown in the figure. This decreasing trend of scintillation activity has been observed to continue in 1986.

Equatorial Irregularities: Important new information on equatorial F-region irregularities associated with plasma depletions, or "bubbles," became available as a result of the clustering of a variety of



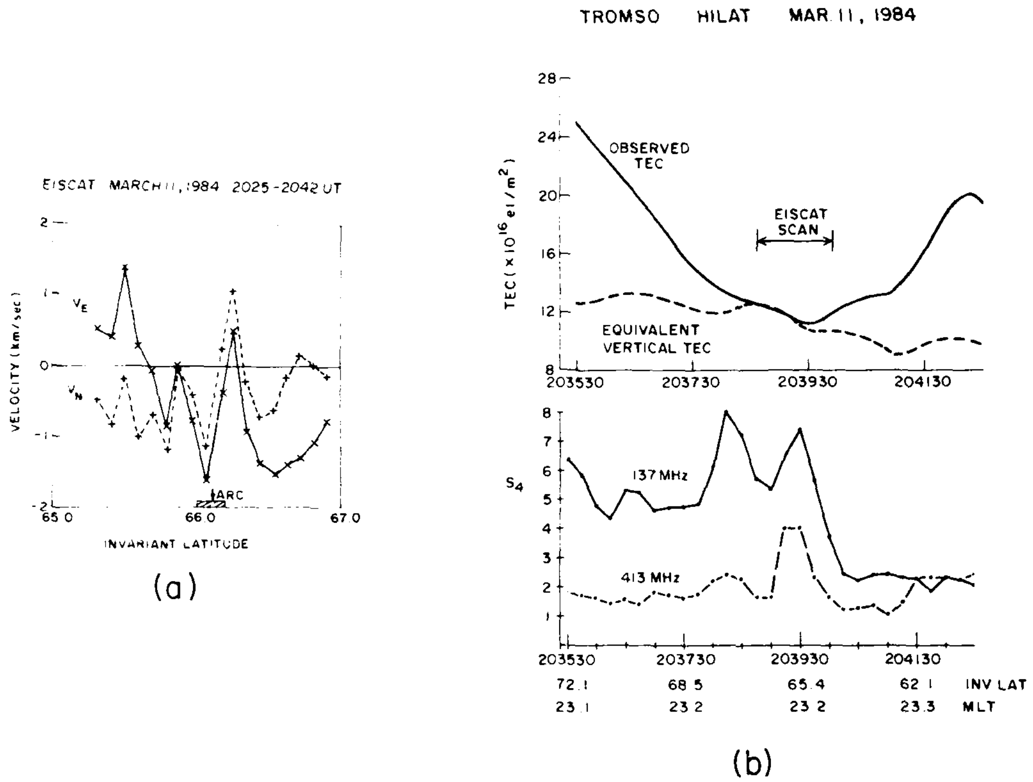
Temporal Variation of the Range and Intensity of 50 MHz Radar Backscatter Observed at Jicamarca (Top). Variation of the Amplitude Scintillation index (S_4) of 1694 MHz Signals from the Geostationary Satellite GOES 5 Recorded at Ancon (Bottom).

techniques including digital sounder, scintillation and radar measurements near the magnetic equator in Peru in conjunction with two F-region rockets launched on March 1 and 14, 1983. Analysis of this data continued during the reporting period. The full complement of equatorial spread F phenomena, namely, the occurrence of bubbles detected by the rockets, 3-m plume structures detected by the Jicamarca radar, and vhf/GHz scintillations, were recorded on both these evenings. The radar backscatter with extended plumes was found to occur in association with maximum 1.7 GHz scintillations as shown in the figure. This established that the height-integrated rms electron density deviation of 200 m scale irregularities causing 1.7 GHz scintillations maximizes in extended 3 m plume structures. The magnitude of 1.7 GHz scintillations recorded at high elevation angles (~76°) near the magnetic equator did not exceed a value of S_4 = 0.2 (4 dB) in contrast to the near saturated 1.5 GHz scintillations routinely observed at Ascension Island near the crests of the equatorial anomaly of F_2 ionization as mentioned earlier. The observed scintillation magnitudes at 1.7 GHz have, however, been found to be compatible with the ambient F-region electron density and the irregularity parameters measured by the rocket. The irregularity drift velocities measured by the spaced receiver scintillation measurements were in general agreement with the radar interferometer results, indicating that both the meter and hundred meter scale irregularities convect together.

A distinct class of equatorial irregularities known as the bottomside sinusoidal (BSS) type has been identified. Unlike equatorial bubbles, these irregularities occur in very large patches, sometimes in excess of several thousand kilometers in the East-West direction and are associated with frequency spread on ionograms. Scintillations caused by such irregularities exist only in the vhf band, exhibit Fresnel oscillations in intensity spectra, providing evidence for a relatively thin irregularity layer, and persist for extremely long durations (as much as several hours) without any interruptions. These irregularities maximize during solstices, so that in the vhf range, scintillation morphology at an equatorial station is determined by considering occurrence characteristics of both bubble type and BSS type irregularities.

Coordinated Measurements of the Nightside Auroral Oval: A distinct class of subkilometer high-latitude irregularities has been identified which can create localized regions of near saturated vhf and fairly intense uhf scintillations in the nighttime auroral F-region. The unique feature of this class of irregularities is that it is associated not with large-scale (several tens of kilometers) organized density gradients in the F-region, such as observed at the edges of plasma blobs, but with velocity shears with shear gradient scale lengths of 10 km. The presence of velocity shears was established by EISCAT ion-drift measurements from the HILAT satellite. The relatively high power of short-scale irregularities distinguishes this class of irregularities, which are observed to cause strong uhf scintillations in the auroral region without associated TEC enhancements (panel B of the figure) and are expected to be sources of hf backscatter. Numerical simulation studies of the velocity-shear-driven Kelvin-Helmholtz instability in the F-region conducted at the Naval Research Laboratory recently show good agreement with the density and electric field spectra observed experimentally with HILAT and Dynamics Explorer-2.

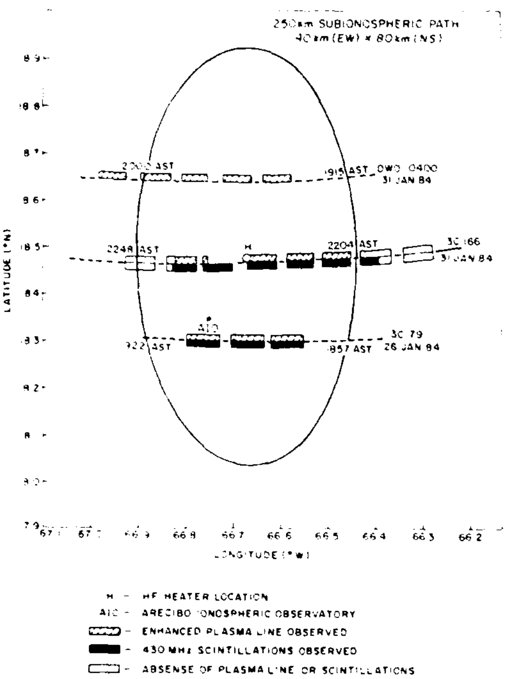
Ionospheric Modification By High Power Radio Waves: The characteristics of self-focusing instability driven by high-power high-frequency radio waves were studied by performing simultaneous radio-star scintillations and enhanced plasma line-intensity measurements by the uhf radar at Arecibo in January, 1984. As shown in the figure both scintillation and enhanced plasma line-intensity fluctuations could be detected over a 6 dB width of the heater beam when the average power density in the F-region was ~50 μWm^{-2}. Considerable East-West asymmetry in the spatial structure of both scintillations and plasma line-intensity fluctuations was observed. Spectral studies of scintillations indicated an erosion of short-scale irregularities as the irregularities were convected downstream. Interesting changes in the fading characteristics as the heating mode was switched from overdense to underdense were also observed.



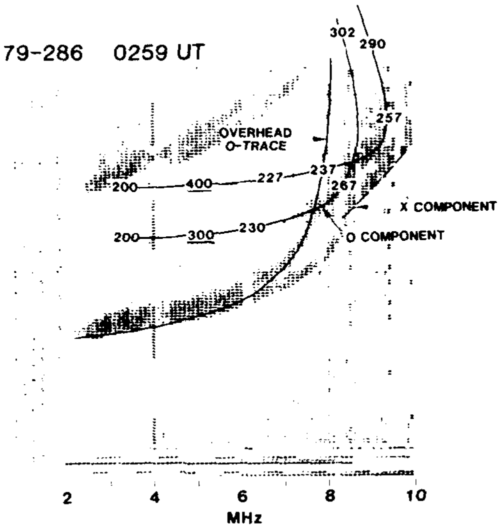
Coordinated EISCAT/HILAT Measurements Showing Presence of Intense VHF/UHF Scintillations in the Absence of "Blobs," or TEC Structure, but in Association with Velocity Shears in the F-region.

During March, 1984, and November, 1985, the high power hf heating facility located at Ramfjordmoen (69.6°N, 19.2°E geographic) near Tromso, Norway, was used to modify the ionospheric F-region, and experiments were performed to study the generation of artificial F-region irregularities in the daytime subauroral environment. For the experiments, 250 MHz transmissions from a quasi-stationary satellite were received at the Tromso telemetry station. The fluctuations of intensity and phase of these transmissions were analyzed to detect the presence of irregularities of F-region electron density caused by the heater. F-region irregularities were excited in the daytime subauroral environment, causing 3dB fluctuations of signal intensity at the 250 MHz transmissions of the quasi-stationary satellite. Spectral analysis showed the excitation of a narrow band structure corresponding to approximately 750 m scale size. Fresnel oscillations in both the phase and intensity spectra provided evidence for a relatively thin irregularity layer.

RF-Heating Diagnostics: Renewed interest in the effects of ionospheric heating by radio frequency energy led to revisiting a data set collected by the AFGL Airborne Ionospheric Observatory during



Subionospheric Tracks of Radio Sources through the Heated Volume on January 26 and 31, 1984. (The cross-hatched areas indicate regions of hf enhanced plasma line echoes; the solid blocks indicate regions of 430 MHz scintillations having a relative power fluctuation > 5 percent. The breaks in the data correspond to calibration intervals. The scintillations using DW0400 were contaminated by radar interference and hence are not shown.)



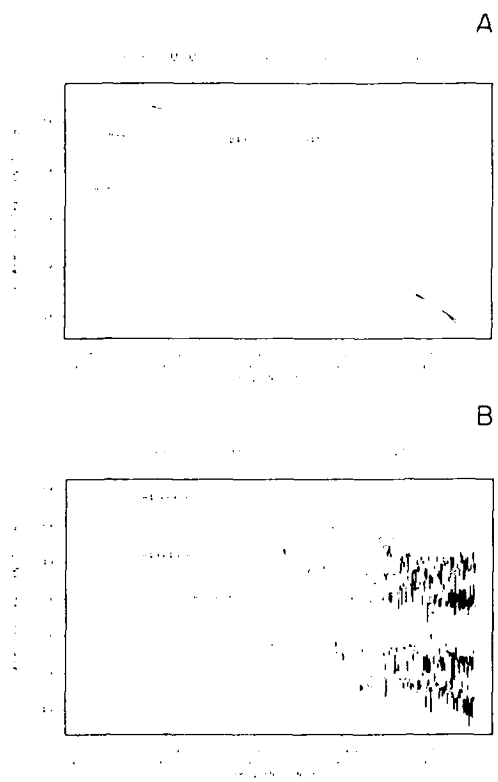
Airborne ionogram taken at a ground range of 375 km to the heater shows 0- and x-component of field-aligned scatter. (The simulated traces (0-component only) result, if field-aligned irregularities filling a vertical column at 300 and 400 km ground range from the aircraft are assumed. The numbers along the simulated traces indicate the height of the irregularities contributing to scatter at the specified ground ranges.)

heating experiments conducted at the NOAA RF Heating Facility at Platteville, Colorado, in October, 1979. Digital ionograms obtained onboard the aircraft during a series of rf-heating experiments showed strong, well-defined backscatter traces (see the figure) which changed location within the ionogram, as well as the sign of the Doppler shift of the backscatter signals, depending on range to the heater facility and the direction of the flight track towards or away from the facility. With 3-D ray tracing simulation, it was possible to synthesize the observed echo traces and to infer the extent of the volume filled with heater-induced irregularities to ±100 km extent in the North-South direction (with respect to the heater location). The structured region had a well defined northern border, and a height extent from the bottom of the F-layer to at least the layer maximum. The AFGL aircraft has been used to define heating effects during campaigns with the Arecibo, Puerto Rico, and EISCAT, Norway, heating facilities.

Maximum Entropy Method: Burg's maximum entropy method (MEM) of power spectral estimation has been exploited and developed intensively at AFGL for the last ten years. Applications at AFGL include magnetic pulsations, sunspot numbers, auroral indices, ionospheric phase and amplitude scintillations, neutral air densities, charged particle velocity, density and electric field measurements, infrared molecular spectrum analysis and mass spectrometry.

Dynamic MEM (a) and Periodogram (b) Power Spectra for a Set of Amplitude Scintillation Data Obtained at Ascension Island from the MARISAT Satellite. (Each spectrum used 361 observations (10 sec), and the start time was slipped by 181 observations (5 sec) for each new data set. The data were quiet from 0-2 minutes, moderately active from 2 to 3.5 minutes, and very active from 3.5 to 5 minutes.

In the Ionospheric Physics Division the emphasis has been on the development of smooth, slowly changing power spectra



Four Successive Spectra Taken from Those Shown on the Previous Figure. (MEM (a) spectra show clearly the changing character of the spectrum from batch B38 to B41. Periodogram spectra (b) of the same data sets are overwhelmed by high levels of spectral noise inherent in the periodogram method.)

for red noise processes such as ionospheric amplitude and phase scintillation, and charged particle observations. In extensive studies at AFGL, MEM has been shown to produce spectra which are optimally smooth, using shorter data sets than required by traditional fast Fourier transform (FFT) based techniques. The MEM spectra are smoother and also display greatly increased frequency resolution. If the underlying physical process is changing with time, then dynamic MEM spectra display increased time resolution as well. The figures show MEM and periodogram methods applied to ionosphere scintillation data. The basic reason for the success of MEM is that instead of making unrealistic assumptions about the behavior of the time series or of the autocorrelation function (ACF) outside of the measurement interval, the method provides a reasonable, infinite extension of the ACF. The Fourier transform of the infinitely extended ACF is the MEM spectrum. Note that because of the nature of MEM spectral analysis, there is absolutely no "spectral leakage," which plagues FFT based techniques and forces the use of artificial devices called spectral windows. There is also no need of spectral smoothing because the MEM spectrum is optimally smooth. Finally, MEM works very well with much shorter data sets than are required by traditional FFT based Fourier techniques.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

ANDERSON, D.N. (AFGL); MENDILLO, M., and HERNITER, B. (Boston Univ., Boston, MA)
A Semi-Empirical Low-Latitude Ionospheric Model
Proc. URSI-IPS Conf. on the Ionosphere and Radio Wave Propagation (10-15 February 1985)

BASU, SU. (Emmanuel Coll., Boston, MA); and BASU, S. (AFGL)
Equatorial Scintillations: Advances Since ISEA-6
J. Atmos. and Terr. Phys. 47 (1985)

BASU, SU. (Emmanuel Coll., Boston, MA); BASU, S. (AFGL); MACKENZIE, E. (Emmanuel Coll., Boston, MA); and WHITNEY, H.E. (AFGL)
Morphology of Phase and Intensity Scintillations in the Auroral Oval and Polar Cap
Radio Sci. 20 (May-June 1985)

BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); VALLADARES, C.E. (SRI International, Menlo Park, CA); DASGUPTA, A. (Univ. of Calcutta, India); and WHITNEY, H.E. (AFGL)
Scintillations Associated with Bottomside Sinusoidal Irregularities in the Equatorial F Region
J. Geophys. Res. 91 (January 1986)

BASU, SU. (Emmanuel Coll., Boston, MA); BASU, S. (AFGL); SENIOR, C. (CNET/CRPE, Saint-Maur-des-Fosses, France); WEIMER, D. (Regis College, Weston, MA); NIELSEN, N. (Max Planck Institut für Aeronomie, Katlenburg-Lindau, FRG); and FOUGERE, P.F. (AFGL)
Velocity Shears and Sub-KM Scale Irregularities in the Nighttime Auroral F-Region
Geophys. Res. Lett. 13 (February 1986)

BASU, S. (AFGL); MACKENZIE, E., BASU, SU., COSTA, E. (Emmanuel Coll., Boston, MA); FOUGERE, P.F., CARLSON, H.C., and WHITNEY, H.E. (AFGL)
UHF Scintillation Parameters in the Polar, Auroral and Equatorial Environments
IEEE Special Issue on Communications (1986)

BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); LABELLE, J. (Cornell Univ., Ithaca, NY); KUDEKI, E. (Univ. of Illinois, Urbana, IL); FEJER, B.G., KELLEY, M.C. (Cornell Univ., Ithaca, NY); WHITNEY, H.E. (AFGL); and BUSHBY,

A. (Instituto Geofisico del Peru, Lima, Peru)
Gigahertz Scintillations and Spaced Receiver Drift Measurements During Project Condor Equatorial F Region Rocket Campaign in Peru
J. Geophys. Res. 91 (1 May 1986)

BISHOP, G.J., KLOBUCHAR, J.A. (AFGL); and DOHERTY, P.H. (Emmanuel Coll., Boston, MA)
Multipath Effects on the Determination of Absolute Ionospheric Time Delay from GPS Signals
Radio Sci. 20 (May-June 1985)

BUCHAU, J. (AFGL); and MCNAMARA, L.F. (Australian Ionospheric Prediction Service, Darlinghurst, Australia)
Simulation of Ionograms Obtained During the October 1979 Platteville Heater Experiment
Radio Sci. 21 (May-June 1986)

BUCHAU, J., WEBER, E.J., ANDERSON, D.N., CARLSON, H.C., MOORE, J.G. (AFGL); REINISCH, B.W. (Univ. of Lowell, Lowell, MA); and LIVINGSTON, R.C. (SRI Internat., Menlo Park, CA)
Ionospheric Structures in the Polar Cap: Their Origin and Relation to 250-MHz Scintillation
Radio Sci. 20 (May-June 1985)

CARLSON, H.C. (AFGL); KILLEEN, T.L. (Space Research Bldg., Ann Arbor, MI); EGLAND, A. (Univ. of Oslo, Oslo, Norway); MCEWEN, D.J. (Univ. of Saskatchewan, Saskatoon, Canada); HEELIS, R. (Univ. of Texas, Richardson, TX); KELLY, J.D. (Radio Physics Lab., Menlo Park, CA); and ROSENBERG, T.J. (Univ. of Maryland, College Park, MD)
Future Cusp Experiments and Their Coordination in *The Polar Cusp*,
ed. by J. A. Holtet and A. Egland, D. Reidel Pub. Co. (1985)

CHANG, T., CREW, G.B. (Massachusetts Inst. of Technology, Cambridge, MA); HERSHKOWITZ, N. (Univ. of Wisconsin, Madison, WI); JASPERSE, J.R. (AFGL); RETTERER, J.M. (Boston College, Newton, MA); and WINNINGHAM, J.D. (Southwest Research Inst., San Antonio, TX)
Transverse Acceleration of Oxygen Ions by Electromagnetic Ion Cyclotron Resonance with Broad Band Left-Hand Polarized Waves
Geophys. Res. Lett. 13 (July 1986)

CREW, G.B., CHANG, T. (Massachusetts Inst. of Tech., Cambridge, MA); RETTERER, J.M. (Boston Coll., Newton, MA); and JASPERSE, J.R. (AFGL)
Analytic Ion Conics in the Magnetosphere
AGU Monograph 38 (1986)

DASGUPTA, A., ANDERSON, D.N., and KLOBUCHAR, J.A.
Modeling the Low Latitude Ionospheric Electron Content
J. Atmos. Terr. Phys. 47 (1985)

DEAKYNE, C.A.
Filling of Solvent Shells about Ions. 2. Isomeric Clusters of $(H_2O)_n(NH_3)H^+$
J. Phys. Chem. 90 (1986)

DEAKYNE, C.A. (AFGL); MEOT-NER, M., and KARPOS, Z. (Natl. Bureau of Standards, Gaithersburg, MD)
Ion Chemistry of Cyanides and Isocyanides. 1. The Carbon Lone Pair as Proton Accepter; Proton Affinities of Isocyanides
J. Am. Chem. Soc. 108 (1986)

DEAKYNE, C.A. (AFGL); MEOT-NER, M., (Natl. Bureau of Standards, Gaithersburg, MD); CAMPBELL, C.L., HUGHES, M.G., and MURPHY, S. P. (Holy Cross Coll., Worcester, MA)
Multicomponent Cluster Ions. I. The Proton Solvated by CH_3CN/H_2O
J. Chem. Phys. 84 (1 May 1986)

DECKER, D.T. (Boston Coll., Newton, MA); DANIELL, R.E. (Computational Physics, Inc., Annandale, VA); JASPERSE, J.R. (AFGL); and

STRICKLAND, D.J. (Computational Physics, Inc., Annandale, VA)
Determination of Ionospheric Electron Density Profiles from Satellite UV Emission Measurements
Proc SPIE 30th An. Internat. Tech. Symp. 687 (November 1986)

DONNELLY, R.F. (NOAA/ERL, Boulder, CO); HINTEREGGER, H.E. (AFGL); and HEATH, D.F. (NASA Goddard Space Flight Ctr., Greenbelt, MD)
Temporal Variations of Solar EUV, UV and 10830-A Radiations
J. Geophys. Res. 91 (1 May 1986)

FOUGERE, P.F.
A Review of the Problem of Spontaneous Line Splitting in Maximum Entropy Power Spectral Analysis in Maximum-Entropy and Bayesian Methods in Inverse Problems.
ed. by C. R. Smith and W.T. Grady, Jr., Reidel Pub. Co. (1985)
Maximum Entropy Spectrum Analysis: A Review of Two Extreme Cases. 1. Narrow Band Processes with Very High Signal to Noise Ratio. 2. Broadband - Red Noise Processes
Proc. Internat. Wkshp on Data Processing (February 1985)
Spectrum Model-Order Determination Via Significant Reflection Coefficients
Proc ICASSP-IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (26-29 March 1985)
Maximum Entropy Spectrum from a Non-Extendable Autocorrelation Function
Proc ICASSP-IEEE Internat. Conf. on Acoustics, Speech and Signal Processing (6-11 April 1986)

GALLAGHER, C.C., FORSBERG, C.A., PIERI, R.V., FAUCHER, G.A., and CALO, J.M.
Nitric Oxide and Nitrogen Dioxide Content of Whole Air Samples Obtained at Altitudes from 12 to 30 KM
J. Geophys. Res. 90 (20 August 1985)

GALLAGHER, C.C., FORSBERG, C.A. (AFGL); MASON, A.S. (Los Alamos Natl. Lab., New Mexico); GANDRUD, B.W. (Natl. Ctr. for Atmospheric Research, Boulder, CO); and

JANGHORBANI, M. (Massachusetts Inst. of Tech., Cambridge, MA)
Total Chlorine Content in the Lower Stratosphere
J. Geophys. Res. 90 (20 October 1985)

HENCHMAN, M. J. (Brandeis Univ., Waltham, MA); HIERL, P.M. (Univ. of Kansas, Lawrence, KS); and PAULSON, J.F. (AFGL)
Nucleophilic Displacement vs Proton Transfer: The System $OH(H_2O)_{0,1,2,3}+CH_3Cl$ in the Relative Energy Range 0.03-5eV
J. Am. Chem. Soc. 107 (1985)

HENCHMAN, M. J. (Brandeis Univ., Waltham, MA); VIGGIANO, A.A., PAULSON, J.F. (AFGL); FREEDMAN, A., and WORMHOUDT, J. (Aerodyne Research, Inc., Billerica, MA)
Thermodynamic and Kinetic Properties of the Metaphosphate Anion, PO_3^- in the Gas Phase
J. Am. Chem. Soc. 107 (1985)

HIERL, P.M., AHRENS, A.F. (Univ. of Kansas, Lawrence, KS); HENCHMAN, M. (Brandeis Univ., Waltham, MA); VIGGIANO, A.A. (System Integration Engineering, Lexington, MA); and PAULSON, J.F. (AFGL)
Nucleophilic Displacement as a Function of Hydration Number and Temperature: Rate Constants and Product Distributions for $OD(D_2O)_{0,1,2,3}+CH_3Cl$ from 200-500K
J. Am. Chem. Soc. 108 (1986)
Proton Transfer as a Function of Hydration Number and Temperature: Rate Constants and Product Distributions for $OH(H_2O)_{0,1,2,3}$ HF at 200-500K + HF at 200-500K
J. Am. Chem. Soc. 108 (1986)

HUNTON, D.E. (AFGL); and CALO, J.M. (Brown University, Providence, RI)
Gas Phase Interactions in the Shuttle Environment
Proc. AIAA Shuttle Environment and Operations II Conf. (13-15 Nov 1985)
Low Energy Ions in the Shuttle Environment Evidence for Strong Ambient-Contaminant Interactions
Planetary Space Sci. 33 (1985)

JASPERSE, J.R. (AFGL); and BASU, B. (Boston Coll., Newton, MA)
The Dielectric Function for the Balescu-Lenard-Poisson Kinetic Equations
Phys. of Fluids 29 (January 1986)

KATAYAMA, D.H.
Direct Observation of Electronic Intramolecular Energy Transfer Through a Large Energy Gap
Phys. Rev. Lett. 54 (18 February 1985)
Propensities for Rotational Energy Transfer in the $B\ ^3\pi_g$ ($v=3$) State of Nitrogen
J. Chem. Phys. 84 (1 February 1986)
The UV Huggins Bands of Ozone
J. Chem. Phys. 85 (1 December 1986)

KATAYAMA, D.H., and DENTAMARO, A.V.
Propensities for Collision Induced Electronic Transitions in a Diatomic Molecule
J. Chem. Phys. 85 (1 September 1986)

KELLEY, M.C., LABELLE, J., KUDEKI, E.J., FEJER, B.G. (Cornell Univ., Ithaca, NY); BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); BAKER, K.D. (Utah St. Univ., Logan, UT); HANUISE, C. (Univ. of Toulon, France); ARGO, P. (Los Alamos Natl. Lab., Los Alamos, NM); WOODMAN, R.F. (Univ. of Michigan, Ann Arbor, MI); SWARTZ, W.E., and FARLEY, D.T. (Cornell Univ., Ithaca, NY); and MERIWETHER, J.W., JR. (Univ. of Michigan, Ann Arbor, MI)
The Condor Equatorial Spread F Campaign: Overview and Results of the Large-Scale Measurements
J. Geophys. Res. 91 (1 May 1986)

KLOBUCHAR, J.A., BISHOP, G. (AFGL); and DOHERTY, P.A. (Emmanuel Coll., Boston, MA)
Total Electron Content and L-Band Amplitude and Phase Scintillation
Proc. AGARD Conf. (3-7 June 1985)

KLOBUCHAR, J.A. (AFGL); RASTOGI, R.G. (Indian Inst. of Geomagnetism, Bombay, India); REDDY, B.M. (Natl. Physical Lab., New Delhi, India); and DASGUPTA, A. (Inst. of Radiophysics and Electronics, Calcutta, India)
A Proposal for a Coordinated Study of the Dynamics of Ionospheric Irregularities over the Magnetic Equator
Proc. 2nd Indo-U.S. Wkshp. on Solar Terr. Phys. (1986)

LAWANDY, N.M., MACFARLANE, D.L., RABINOVICH, W.S. (Brown Univ., Providence, RI); and KATAYAMA, D. (AFGL)
Two-Photon Hysteresis in a Nonlinear Fabry-Perot Etalon Containing Rhodamine 6G: Methanol Solutions
Infrared Phys. 25 (1985)

LEE, M.C. (Massachusetts Inst. of Tech., Cambridge, MA); CARLSON, H.C. (AFGL); and KUO, S.P. (Polytechnic Inst. of New York, Farmingdale, NY)
Ionospheric Modifications by HF Heaters
Proc. AGARD Mtg. (3-7 June 1985)

LEE, M.C. (Massachusetts Inst. of Tech., Cambridge, MA); CARLSON, H.C., KLOBUCHAR, J.A., and WEBER, E.J. (AFGL)
Formation and Detection of High-Latitude Ionospheric Irregularities
Proc. AGARD Mtg. (3-7 June 1985)

LOWRANCE, J.L. (Princeton Scientific Instruments, Princeton, NJ); and STERGIS, C.G. (AFGL)
Imaging in the Middle Ultraviolet
Proc. SPIE 30th An. Internat. Tech. Symp. (17-22 August 1986)

MENG, C.-I. (The Johns Hopkins Univ., Laurel, MD); HUFFMAN, R.E., SKRIVANEK, R.A. (AFGL); STRICKLAND, D.J., and DANIELL, R.E., JR. (Computational Physics, Inc., Annandale, VA)
Remote Sensing of Ionosphere by Using Ultraviolet and Visible Emissions
Proc. 30th Tech. Symp. of Soc. of Photo-Optical Instrumentation Engineers (22 August 1986)

MERIWETHER, J.W., JR. (Univ. of Michigan, Ann Arbor, MI); BIONDI, M.A. (Univ. of Pittsburgh, Pittsburgh, PA); and ANDERSON, D.N. (AFGL)
Equatorial Airglow Depletions Induced by Thermospheric Winds
Geophys. Res. Lett. 12 (August 1985)

MULLEN, J.P., MACKENZIE, E., BASU, S. and WHITNEY, H.
UHF GHz Scintillation Observed at Ascension Island from 1980 Through 1982
Radio Sci. 26 (May-June 1985)

PAULSON, J.F., VIGGIANO, A.A., HENCHMAN, M., and DALE, F.
Studies of Negative Ion Reactions: Solvated Ions and Strong Acids
Proc. SASP Symp. on Atomic and Surface Phys (9-15 February 1986)

REINISCH, B.W. (Univ. of Lowell, Lowell, MA); BUCHAU, J., and WEBER, E.J. (AFGL)
Digital Ionosonde Observations of the Polar Cap F-Region Convection
COSPAR Conf. Proc. (30 June-7 July 1986)

RETTERER, J.M. (Boston Coll., Newton, MA); CHANG, T. (Massachusetts Inst. of Tech., Cambridge, MA); and JASPERSE, J.R. (AFGL)
Ion Acceleration by Lower Hybrid Waves in the Supraruroral Region
J. Geophys. Res. 91 (1 February 1986)
Plasma Simulation of Ion Acceleration by Lower Hybrid Waves in the Supraruroral Region
AGU Monograph 38 (1986)

RETTERER, J.M. (Boston Coll., Newton, MA); JASPERSE, J.R. (AFGL); and CHANG, T.S. (Massachusetts Inst. of Tech., Cambridge, MA)
The Loss-Cone Population in the Magnetosphere: A Boundary-Layer Description
Physics of Space Plasmas 5 (1982-1984)

SCHENKEL, F.W., OGORZALEK, B.S. (Applied Physics Lab., Laurel, MD);

LARRABEE, J.C., LEBLANC, F.J., and HUFFMAN, R.E. (AFGL)
Ultraviolet Daytime Auroral and Ionospheric Imaging from Space
Appl. Opt. 24 (15 October 1985)

STERGIS, C.G.
Atmospheric Transmission in the Middle Ultraviolet
Proc. SPIE 30th An. Internat. Tech. Symp. (17-22 August 1986)

SWIDER, W.
Ionic Mobility of the Middle Atmosphere
Adv. Space Res. 4 (1984)
Enhanced Variations for Chemical Rates with Inverse Temperature Dependencies: Application to Seasonal Abundance of Mesospheric Sodium
Geophys. Res. Lett. 12 (September 1985)
Mesospheric Sodium: Implications Using a Steady-State Model
Planetary and Space Sci. 34 (1986)
Sodium Nightglow: Chemically Independent of Sodium Content
J. Geophys. Res. 91 (20 May 1986)

THOMAS, T.F. (Univ. of Missouri, Kansas City, MO); DALE, F., and PAULSON, J.F. (AFGL)
The Photodissociation Spectrum of SO_2^+
J. Chem. Phys. 84 (1 February 1986)

VIGGIANO, A.A.
The Temperature Dependence of Ion Molecule Association Rate Coefficients in the Low Pressure Limit
J. Chem. Phys. 84 (1 January 1986)

VIGGIANO, A.A., DALE, F., and PAULSON, J.F.
Measurements of Some Stratospheric Ion-Molecule Association Rates: Implications for Ion Chemistry and Derived HNO_3 Concentrations in the Stratosphere
J. Geophys. Res. 90 (20 August 1985)

VIGGIANO, A.A., PAULSON, J.F., and DALE, F.
Reactions of $H^+(H_2O)_n$ with Polar Molecules
Proc. NATO Summer School on Ion Chem. (29 June-11 July 1986)

VIGGIANO, A.A., PAULSON, J.F., DALE, F., HENCHMAN, M. (AFGL); ADAMS, N.G., and SMITH, D. (Univ. of Birmingham, Birmingham, England)
Ion Chemistry and Electron Affinity of WF_6
J. Phys. Chem. 89 (1985)

WEBER, E.J., and BUCHAU, J.
Observations of Plasma Structure and Transport at High Latitudes in *The Polar Cusp*,
ed. by J.A. Holtet and A. Egland, D. Reidel Pub. Co. (1985)

WEBER, E.J. (AFGL); TSUNODA, R.T. (SRI Internat., Menlo Park, CA); BUCHAU, J. (AFGL); SHEEHAN, R.E. (Boston Coll., Newton, MA); STRICKLAND, D.J. (Computational Physics, Inc., Annandale, VA); WHITING, W. (Regis Coll., Weston, MA); and MOORE, J.G. (AFGL)
Coordinated Measurements of Auroral Zone Plasma Enhancements
J. Geophys. Res. 90 (1 July 1985)

WEBER, E.J., KLOBUCHAR, J.A., BUCHAU, J., CARLSON, H.C. (AFGL); LIVINGSTON, R.C., DE LA BEAUJARDIERE, O., MCCREADY, M. (SRI International, Menlo Park, CA); MOORE, J.G., and BISHOP, G.J. (AFGL)
Polar Cap F-Layer Patches: Structure and Dynamics
J. Geophys. Res. 91 (1 November 1986)

PRESENTATIONS
JANUARY, 1985 - DECEMBER, 1986

ANDERSON, D.N.
Calculated Rayleigh-Taylor Growth Rates for Solar Minimum and Solar Maximum Conditions
North Am. Radio Sci. Mtg., Vancouver, Canada (15-17 June 1985)
Solar Cycle Dependence of Nighttime East-West Plasma Drift Velocity at Low Latitudes
AGU Mtg., San Francisco, CA (8-12 December 1986)

ANDERSON, D.N. (AFGL); MENDILLO, M., and HERNITER, G. (Boston Univ., Boston, MA)
Total Electron Content Maps from SLIM
Internat. Beacon Satellite Symp., Oulu, Finland (9-13 June 1986)

ANDERSON, D.N. (AFGL); ABREU, V.J. (Univ. of Michigan, Ann Arbor, MI); MENDILLO, M., and HERNITER, B. (Boston Univ., Boston, MA)
Calculated and Observed 6300 A Equatorial Airglow Intensities
AGU Mtg., San Francisco, CA (9-13 December 1985)

ANDERSON, D.N., BUCHAU, J., WEBER, E.J., and CARLSON, H.C.
Calculated and Observed Wintertime NMAX(F2) Values at Thule
Natl. Radio Sci. Mtg., Boulder, CO (13-16 January 1986)

BABCOCK, L.M., HERD, C.R. (Louisiana St. Univ., Baton Rouge, LA); VIGGIANO, A.A., and PAULSON, J.F. (AFGL)
Radiative Stabilization in Ion-Molecule Addition Reactions
33rd An. Conf. on Mass Spectrometry and Allied Topics, San Diego, CA (27-31 May 1985)
Halide Ion Addition to BF_3 and BCl_3
10th Internat. Mass Spectrometry Conf., Swansea, UK (9-13 September 1985)

BALLENTHIN, J.O.
Positive Ion Mass Distribution Between 29 KM and 38 KM Altitude
AGU Mtg., San Francisco, CA (9-13 December 1985)
Ion Composition and Structure in a Sun-Aligned Polar Cap Arc
AGU Mtg., Baltimore, MD (19-23 May 1986)

BASU, B. (Boston Coll., Newton, MA); and JASPERSE, J.R. (AFGL)
Ion-Acoustic Instability in a Two- Temperature Collisional Plasma Without Any Current
APS Div. of Plasma Physics An. Mtg., Baltimore, MD (3-7 November 1986)
Ion-Acoustic Instability in a Weakly Collisional Two-Temperature Plasma Without Any Current
AGU Mtg., San Francisco, CA (8-12 December 1986)

BASU, B. (Boston Coll., Newton, MA); JASPERSE, J.R. (AFGL); ROBINSON, R.M., VONDRAK, R.R., and EVANS, D. (Lockheed, Palo Alto, CA)
Linear Transport of Auroral Proton and H-Atom Precipitation: A Comparison with Observations
AGU Mtg., San Francisco, CA (9-13 December 1985)

BASU, S. (AFGL); and BASU, SU. (Emmanuel Coll., Boston, MA)
Scintillations Induced by HF Heating at Middle and Subauroral Latitudes
Natl. Radio Sci. Mtg., Boulder, CO (13-16 January 1986)

BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); and COLEY, W.R. (Univ. of Texas, Richardson, TX)
Temporal Structure of Satellite Signals on Ground and Spatial Structures of Density and Velocity in the Ionosphere at the Crest of the Equatorial Anomaly
AGU Mtg., Baltimore, MD (19-23 May 1986)

BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); and SULZER, M.P. (Arecibo Obs., NAIC, Arecibo, PR)
Simultaneous Plasma Line and Radio Star Scintillation Observations at Arecibo During Ionospheric Modification by HF Waves
Symp. on Ionosphere Modification by Power Radio Waves, Moscow, USSR (8-12 September 1986)

BASU, SU. (Emmanuel Coll., Boston, MA); BASU S., CARLSON, H.C. (AFGL); and STUBBE, P. (MPI für Aeronomie, Lindau, FRG)
Generation of Ionospheric Irregularities at Sub-Auroral Latitudes Caused by High Power Radio Waves
Symp. on Ionosphere Modification by Power Radio Waves, Moscow, USSR (8-12 September 1986)

BASU, SU., COSTA, E. (Emmanuel Coll., Boston, MA); BASU, SANTIMAY, FOUGERE, P.F. (AFGL); COLEY, W.R., and HEELIS, R.A. (Univ. of Texas, Richardson, TX)
Comparison of Spaced Receiver Drift Measurements at High Latitudes with Convection Patterns Derived from DE-2
Natl. Radio Sci. Mtg., Boulder, CO (13-16 January 1986)

BASU, SU., MACKENZIE, E. (Emmanuel Coll., Boston, MA); BASU, SANTIMAY, HARDY, D.H., RICH, F.J., and KLOBUCHAR, J.A. (AFGL)
Morphology of Scintillation/TEC, Exospheric Density and Particle Precipitation in the Auroral Ionosphere
AGU Mtg., Baltimore, MD (19-23 May 1986)

BASU, S. (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); COLEY, W.R., HEELIS, R.A. (Univ. of Texas, Richardson, TX); CARLSON, H.C., MAYNARD, N. (AFGL); and LIN, C.S. (Southwest Research Inst., San Antonio, TX)
Density and Electric Field Turbulence in the Dayside Cusp and Winter Polar Cap
IAGA Mtg., Prague, Czechoslovakia (4-12 August 1985)

BASU, S., (AFGL); BASU, SU. (Emmanuel Coll., Boston, MA); SENIOR, C. (CNET/CRPE, Saint-Maur-des-Fosses, France); CARLSON, H.C., HARDY, D.H., RICH, F.J. (AFGL); and

NIELSEN, E. (Max Planck Institut für Aeronomie Katlenburg-Lindau, FRG)
HILAT/EISCAT/STARE Case Study of F-Region Irregularities in the Nighttime Auroral Oval
IAGA Mtg., Prague, Czechoslovakia (4-12 August 1985)

BASU, SU., MCKENZIE, E. (Emmanuel Coll., Boston, MA); BASU, S., MAYNARD, N., FOUGERE, P.F. (AFGL); COLEY, W.R., HEELIS, R.A., HANSON, W.B. (Univ. of Texas, Dallas, TX); WINNINGHAM, J.D., LIN, C.S. (Southwest Research Inst., TX); HOEGY, W.R., and LEDLEY, B.G. (Goddard Space Flight Ctr., Greenbelt, MD)
Simultaneous Density and Electric Field Fluctuation Spectra Associated with Velocity Shears in the Auroral Oval
AGU Mtg., San Francisco, CA (8-12 December 1986)

CARLSON, H.C.
Constraints by Aeronomy on the Plasma Physics of HF Heater Accelerated Electrons
Natl. Radio Sci. Mtg., Boulder, CO (13-16 January 1986)
Equinox Transition Study (ETS)
Internat. Symp. on Large-Scale Processes in the Ionospheric-Thermospheric System, Boulder, CO (2-5 December 1986)

CARLSON, H.C. (AFGL); OLIVER, W., and SALAH, J. (Haystack Obs., Westford, MA)
Initial Results from the September 1984 ETS Campaign
Internat. Symp. on Large-Scale Processes in the Ionospheric-Thermospheric System, Boulder, CO (2-5 December 1986)

CARLSON, H.C., WEBER, E.J., BUCHAU, J., and ANDERSON, D.N.
Polar Ionospheric Weather
Internat. Symp. on Large-Scale Processes in the Ionospheric-Thermospheric System, Boulder, CO (2-5 December 1986)

COSTA, E. (Emmanuel Coll., Boston, MA), and FOUGERE, P.F. (AFGL)
Spaced Receiver Analysis in the Spectral Domain
Natl. Radio Sci. Mtg., Boulder, CO (13-16 January 1986)

COSTA, E., BASU, SU. (Emmanuel Coll., Boston, MA); and FOUGERE, P.F. (AFGL)
MEM and FFT Analysis of High-Latitude Spaced-Receiver Measurements
DNA HILAT Mtg., Washington, DC (7-8 May 1985); North Am. Radio Sci. Mtg. and Internat. IEEE/AP-S Symp., Vancouver, Canada (17-21 June 1985)

COSTA, E. (Emmanuel Coll., Boston, MA); FOUGERE, P.F. (AFGL); and BASU, SU. (Emmanuel Coll., Boston, MA)
Spaced-Receiver Analysis of Intensity and Phase Scintillation Data
North Am. Radio Sci Mtg., and Internat. IEEE/AP-S Symp., Vancouver, Canada (17-21 June 1985)

CREW, G.B. (Massachusetts Inst. of Tech., Cambridge, MA); RETTERER, J.M. (Boston Coll., Newton, MA); CHANG, T.S. (Massachusetts Inst. of Tech., Cambridge, MA); and JASPERSE, J.R. (AFGL)
The Modeling of Ion Acceleration by Electromagnetic Ion Cyclotron Resonance
AGU Mtg., Baltimore, MD (19-23 May 1986)

DANDEKAR, B.S.
Improving foF2 Predictions for Sunrise Hours
AGU Mtg., Baltimore, MD (27-31 May 1985)

DEAKYNE, C.A. (AFGL); and MEOT-NER, M. (Natl. Bureau of Standards, Gaithersburg, MD)
A Molecular Orbital Study of $(NH_3)_n(HCN)_mH^+$ Cluster Ions
191st Natl. Mtg. of the Am. Chem. Soc., New York, NY (13-18 April 1986)

DECKER, D.T. (Boston Coll., Newton, MA); and JASPERSE, J.R. (AFGL)
Modeling the Midlatitude Daytime Airglow and Electron Density Profile: A Parameter Study
AGU Mtg., Baltimore, MD (19-23 May 1986)

DECKER, D.T. (Boston Coll., Newton, MA); JASPERSE, J.R. (AFGL); KOZYRA, J.U., NAGY, A.F. (Univ. of Michigan, Ann Arbor, MI); and WINNINGHAM, J.D. (Southwest Res., San Antonio, TX)
Modeling Energetic Ionospheric Photoelectrons
AGU Mtg., San Francisco, CA (8-12 December 1986)

DENTAMARO, A.V., and KATAYAMA, D.H.
Collision Induced Electronic Transitions in a Diatomic Molecule II. Theoretical Interpretations
Joint Div. Mtg. of Am. Phys. Soc., Eugene, OR (18-20 June 1986)

FOUGERE, P.F.
Maximum Entropy Spectrum Analysis: A Review of Two Extreme Cases. 1. Narrow Band Processes with Very High Signal to Noise Ratio. 2. Broadband-Red Noise Processes
Internat. Wkshp. on Data Processing, Colaba, Bombay, India (February 1985)
Application of Maximum Entropy Spectrum Estimation to Air Force Problems
Third ASSP Spectrum Estimation Wkshp., Boston, MA (November 1986)

HENCHMAN, M.J.
What Can One Learn from Studying the Reactions of Selectively Solvated Ions?
189th Am. Chem. Soc. Natl. Mtg., Miami, FL (28 April-3 May 1985)
Should One Use the Average-Dipole Orientation Theory or the Adiabatic Capture Centrifugal Sudden Approximation Theory for Predicting the Rate Constants of Ion-Molecule Reaction?
Seventh East Coast ICR and Ion Chemistry Mtg., Newark, DE (19 October 1985)
The Chemistry of Gaseous Ions
Brotherton Research Lectures, Leeds, UK (2-15 February 1986)
Gas Phase Approaches to Biochemistry: The Incredible Story of PO_3
Univ. of Birmingham, UK, Colloq. (19 February 1986)
Reactivity as a Function of Solvation Number
191st Am. Chem. Soc. Natl. Mtg., New York, NY (13-17 April 1986)

HENCHMAN, M.J. (AFGL); HIERL, P.M. (Univ. of Kansas, Lawrence, KS); and PAULSON, J.F. (AFGL)
Nucleophilic Displacement in the Gas Phase as a Function of Temperature, Translational Energy and Solvation Number
190th Mtg. of the Am. Chem. Soc., Chicago, IL (8-13 September 1985)

HENCHMAN, M.J., VIGGIANO, A.A., PAULSON, J.F. (AFGL); HIERL, P.M., and AHRENS, A.F. (Univ. of Kansas, Lawrence, KS)
Reactivity of Ionic Clusters as a Function of Temperature and Cluster Size
Gordon Research Conf., Plymouth, NH (12-16 August 1985)

HIERL, P.M., AHRENS, A.F. (Univ. of Kansas, Lawrence, KS); HENCHMAN, M.J., VIGGIANO, A.A., and PAULSON, J.F. (AFGL)
Rate Constants and Product Distributions as Functions of Temperature for the Reaction of $OH(H_2O)$ with CH_3CN
8th Rocky Mountain Regional Mtg. of ACS, Denver, CO (9-12 June 1986)

HIERL, P.M. (Univ. of Kansas, Lawrence, KS); HENCHMAN, M.J., VIGGIANO, A.A. (AFGL); AHRENS, A.F. (Univ. of Kansas, Lawrence, KS); and PAULSON, J.F. (AFGL)
Effects of Temperature and Reactant Solvation upon the Rates of Ion-Molecule Reactions
33rd An. Conf. on Mass Spectrometry and Allied Topics, San Diego, CA (27-31 May 1985)
How Does Solvation Affect Reactivity?
Internat. Conf. on Chem. Kinetics, Gaithersburg, MD (17-19 June 1985)

HUFFMAN, R.E.
Ultraviolet Aurora from Space
Space Sci. Sem., Boston, MA (25 October 1985); IAGA Conf., Prague, Czechoslovakia (7-14 August 1985)
Introduction to Ultraviolet Radiation/Tutorial Presentation
SPIE Conf. on Optical and Optoelectronic Applied Sciences and Engineering, San Diego, CA (17-22 August 1986)

HUFFMAN, R.E. (AFGL); CONWAY, R.R., and MEIER, R.R. (Naval Research Lab., Washington, DC)
S3-4 Satellite Observations of the OI 1641Å Airglow: Implications for the Latitudinal Variation of Atomic Oxygen
AGU Mtg., San Francisco, CA (8-12 December 1986)

HUFFMAN, R.E. (AFGL); ISHIMOTO, M., and MENG, C.-I. (The Johns Hopkins Univ., Laurel, MD)
Auroral Morphological Analysis of Far and Near UV Spectra
AGU Mtg., San Francisco, CA (8-12 December 1986)

HUFFMAN, R.E., LARRABEE, J.C., and LEBLANC, F.J.
Ultraviolet Limb Radiance Measurements from Shuttle
AGU Mtg., San Francisco, CA (9-13 December 1985)

HUFFMAN, R.E., LARRABEE, J.C., DELGRECO, F.P. (AFGL); MENG, C.-I., SCHENKEL, F.W., and OGORZALEK, B.S. (The Johns Hopkins Univ., Laurel, MD)
Ultraviolet and Visible Atmospheric Imaging Experiment Onboard the Polar Bear Satellite
AGU Mtg., San Francisco, CA (8-12 December 1986)

HUNTON, D.E., SWIDER, W. (AFGL); and CALO, J.M. (Brown Univ., Providence, RI)
Variations of Water Concentrations in the Shuttle Environment
AGU Mtg., San Francisco, CA (9-13 December 1985)

HUNTON, D.E., VIGGIANO, A.A., SWIDER, W., PAULSON, J. F., and SHERMAN, C.
Mass Spectrometric Measurements of SF_6 Chemical Releases from Sounding Rockets
AGU Fall Mtg., San Francisco, CA (8-12 December 1986)

HUNTON, D.E., TRZCINSKI, E. (AFGL); CROSS, J.B., SPANGLER, L.H., ARCHULETA, F.H. (Los Alamos Natl. Lab., Los Alamos, NM); and VISENTINE, J.T. (NASA Johnson Space Ctr., Houston, TX)
Quadrupole Mass Spectrometer for Space Shuttle Applications: Flight Capabilities and Ground Calibration
18th Natl. SAMPE Tech. Conf., Seattle, WA (7-9 October 1986)
Mass Spectrometers and Atomic Oxygen
NASA Wkshp. on Atomic Oxygen Effects, Pasadena, CA (10-11 November 1986)

JASPERSE, J.R.
Models of Proton Aurora Emission
IAGA Fifth Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985); CNET/CNRS Mtg., Saint-Maur-des-Fosses, France (20-22 August 1985)

JASPERSE, J.R., and BASU, B.
Exact Solutions for the Thermal Density Fluctuation Spectra in a Weakly Collisional Electron-Ion Plasma
STATPHYS-16 Mtg., Boston, MA (10-16 August 1986)
Exact Solutions for the Dielectric Function and Thermal Density Fluctuation Spectra in a Weakly Collisional Electron-Ion Plasma
APS Div. of Plasma Physics An. Mtg., Baltimore, MD (3-7 November 1986)

JASPERSE, J.R. (AFGL); DECKER, D.T. (Boston Coll., Newton, MA); and HUFFMAN, R.E. (AFGL)
A Study of Coincident Airglow and Electron Density Data
AGU Mtg., Baltimore, MD (19-23 May 1986)

KATAYAMA, D.H.
The Collisional Quenching of Electronically Excited Nitrogen
40th Molecular Symp., Columbus, OH (17-21 June 1985)
Rotational Energy Transfer in the Electronically Excited $B^3\pi_g$ State of N_2
Thirty-Eighth An. Gaseous Electronics Conf., Monterey, CA (15-18 October 1985)

KATAYAMA, D.H., and DENTAMARO, A.V. (AFGL)
Collision Induced Electronic Transitions in a Diatomic Molecule I. Experimental Results
Joint Div. Mtg. of Am. Phys. Soc., Eugene, OR (18-20 June 1986)

KLOBUCHAR, J.A.
Design and Characteristics of the GPS Ionospheric Time Delay Algorithm for Single Frequency Users
Position Location and Navigation Symp., Las Vegas, NV (4-7 November 1986)

KLOBUCHAR, J.A. (AFGL); and ABDU, M.A. (Instituto de Pesquisas Espaciais, Sao Jose dos Campos, Brazil)
Equatorial Ionospheric Irregularities Produced by the Brazilian Ionospheric Modification (BIME) Experiment
COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

KLOBUCHAR, J.A., ANDERSON, D.N., BISHOP, G.J. (AFGL); and DOHERTY, P.H. (Emmanuel Coll., Boston, MA)
Measurements of Trans-Ionospheric Propagation Parameters in the Polar Cap Ionosphere
Internat. Beacon Satellite Symp., Oulu, Finland (9-14 June 1986)

KLOBUCHAR, J.A., BISHOP, B., WEBER, E., FOUGERE, P. (AFGL); and DOHERTY, P.H. (Emmanuel Coll., Boston, MA)
Transionospheric Radiowave Propagation Effects in the Polar Ionosphere
North Am. Radio Sci. Mtg., Vancouver, Canada (15-17 June 1985)

LARRABEE, J.C., HUFFMAN, R.E. (AFGL); CONWAY, R.R., MEIER, R.R., and PRINZ, D.K. (Naval Research Lab., Washington, DC)
S3-4 Satellite Observations of the N_2 Lyman-Birge-Hopfield System Airglow: Orbital Variation of Vibrational Distribution
AGU Mtg., San Francisco, CA (8-12 December 1986)

LEE, M.C. (Massachusetts Inst. of Tech., Cambridge, MA); CARLSON, H.C. (AFGL); and KUO, S.P. (Polytechnic Inst. of New York, Farmingdale, NY)
Polar Ionospheric Irregularities and Possible Source Mechanisms
North Am. Radio Sci. Mtg., Vancouver, Canada (June 1985)

PAULSON, J.F., VIGGIANO, A.A., and HENCHMAN, M.J.
Strong Acids and High Electron Affinities
38th An. Gaseous Electronics Conf., Monterey, CA (15-18 October 1985)
Ionic Clusters: Reactivity as a Function of Temperature and Cluster Size
191st Natl. Mtg. of the Am. Chem. Soc., New York, NY (13-17 April 1986)

PAULSON, J.F., VIGGIANO, A.A., HENCHMAN, M., and DALE, F.
Studies of Negative Ion Reactions: Solvated Ions and Strong Acids
5th Symp. on Atomic and Surface Physics, Obertraun, Austria (9-15 February 1986)

PAULSON, J.F., DALE, F., VIGGIANO, A.A., HENCHMAN, M. (AFGL); ADAMS, N.G., and SMITH, D. (Univ. of Birmingham, UK)
The Reaction of O^+ with CO_2
Am. Chem. Soc. Regional Mtg., Denver, CO (9-12 June 1986)

REINISCH, B.W. (Univ. of Lowell, Lowell, MA); BUCHAU, J. (AFGL); DOZOIS, C.G. (Univ. of Lowell, Lowell, MA); and WEBER, E.J. (AFGL)
Spaced Antenna HF Doppler Observations of F-Region Drifts in the Polar Cap and the Auroral Zone
North Am. Radio Sci. Mtg., Vancouver, Canada (17-21 June 1985)

RETTERER, J.M. (Boston Coll., Newton, MA); CHANG, T. (Massachusetts Inst. of Tech., Cambridge, MA); and JASPERSE, J.R. (AFGL)
Ion Acceleration by Lower Hybrid Waves in the Supraauroral Region
Chapman Conf., Wellesley, MA (June 1985)
Counterstreaming Electron Acceleration by VLF Turbulence in the Supraauroral Region
AGU Mtg., San Francisco, CA (9-13 December 1985)

RETTERER, J.M., DECKER, D.T. (Boston Coll., Newton, MA); STRICKLAND, D.J. (CPI, Inc., Annandale, VA); and JASPERSE, J.R. (AFGL)
On Modeling Diffuse Auroral Electron Precipitation and Atmospheric Backscatter
First Huntsville Wkshp. on Magnetosphere/ Ionosphere Plasma Models, Guntersville, AL (13-16 October 1986)

SCHENKEL, F.W., OGORZALEK, B.S., GARDNER, R.R., HUTCHINS, R.A. (The Johns Hopkins Univ., Laurel, MD); HUFFMAN, R.E., and LARRABEE, J.C. (AFGL)
Simultaneous Multi-Spectral Narrow Band Auroral Imagery from Space (1150Å to 6300Å)
SPIE Conf. on Optical and Optoelectronic Applied Sciences and Engineering, San Diego, CA (17-22 August 1986)

STERGIS, C.G.
Atmospheric Transmission in the Middle Ultraviolet
SPIE Internat. Tech. Symp., San Diego, CA (17-22 August 1986)

STRICKLAND, D.J. (Computational Physics, Inc., Annandale, VA); JASPERSE, J.R. (AFGL); WADZINSKI, H.T. (Bedford Research Assoc., Bedford, MA); and DANIELL, R.E. (Computational Physics, Inc., Annandale, VA)
Proton-Hydrogen-Electron Aurora - Modeling of Distribution Functions, Excitation and Ionization Rates and Optical Emissions
AGU Mtg., San Francisco, CA (9-13 December 1985)

SU, T. (Southeastern Massachusetts Univ., N. Dartmouth, MA); SU, A.C.L. (duPont Co., Wilmington, DE); VIGGIANO, A.A., and PAULSON, J.F. (AFGL)
Gas Phase Ion Molecule Reactions of Perfluoroolefins
7th Winter Fluorine Conf., Orlando, FL (February 1985)

SWIDER, W.
Steady-State Model for Mesospheric Sodium
AGU Mtg., Baltimore, MD (27-31 May 1985)
Sodium Nightglow and Content: Independent Behaviors
AGU Mtg., San Francisco, CA (9-13 December 1985)
Chemistry of the Mesospheric Potassium Layer
AGU Mtg., San Francisco, CA (8-12 December 1986)

SWIDER, W., HUNTON, D.E., and TRZCINSKI, E.
Contaminant Gases in the Shuttle Environment
AGU Mtg., Baltimore, MD (19-23 May 1986)
Estimates of Slant Water Content for the 4th Shuttle Flight
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

VIGGIANO, A.A., and PAULSON, J.F.
Three-Body Association Rate Coefficients as a Function of Temperature and Cluster Size
Internat. Conf. on Chem. Kinetics, Gaithersburg, MD (17-19 June 1985)
Predicting the Temperature Dependences on Ion-Molecule Association Reactions in the Low Pressure Limit
38th An. Gaseous Electronics Conf., Monterey, CA (15-18 October 1985)

VIGGIANO, A.A., DALE, F., and PAULSON, J.F.
Measurements of Ion Molecule Reaction Rates Pertinent to Atmospheric Trace Gas Detection
AGU Mtg., San Francisco, CA (8-12 December 1986)

VIGGIANO, A.A., DEAKYNE, C.A., and PAULSON, J.F.
Neutral Reactions on Ions
9th Internat. Symp. on Gas Kinetics, Bordeaux, France (20-25 July 1986)

VIGGIANO, A.A., HENCHMAN, M., and PAULSON, J.F.
Superacidity
Western Regional Conf. on Gaseous Ion Chemistry, Lake Arrowhead, CA (3-5 January 1986)
Superacidity in the Gas Phase
Superacid Chem. Mtg., Los Angeles, CA (20-21 February 1986)

VIGGIANO, A.A., PAULSON, J.F., and HENCHMAN, M.
Reactions of Solvated Ions
8th Am. Chem. Soc. Mtg., Denver, CO (8-12 June 1986)

VIGGIANO, A.A., PAULSON, J.F., HENCHMAN, M. (AFGL); BABCOCK, L., and HERD, C. (Louisiana St. Univ., Baton Rouge, LA)
Radiative Association: A + B → AB + hν, at 0.1 to 1 torr
Internat. Conf. on Chem. Kinetics, Gaithersburg, MD (17-19 June 1985)

WADZINSKI, H.T. (Bedford Research Assoc., Bedford, MA); JASPERSE, J.R., HUFFMAN, R.E. (AFGL); STRICKLAND, D.J., and DANIELL, R.E. (Computational Physics, Inc., Annandale, VA)
Proton-Hydrogen-Electron Auroral - Analysis of FUV Data from Satellite S3-4
AGU Mtg., San Francisco, CA (9-13 December 1985)

WEBER, E.J., CARLSON, H.C., SMIDDY, M. (AFGL); and KELLEY, M.C. (Cornell Univ., Ithaca, NY)
Electric Field Measurements Within a Polar Cap Aurora
AGU Mtg., San Francisco, CA (8-12 December 1986)

WEBER, E.J., CARLSON, H.C., BALLENTHIN, J., HARDY, D.A., MAYNARD, N.C., McMAHON, W., MOORE, J.G., SMIDDY, M. (AFGL); RODRIGUEZ, P. (Naval Research Lab., Washington, DC); PFAFF, R.F. (Cornell Univ., Ithaca, NY); and GOUGH, P. (The Univ. of Sussex, Brighton, UK)
Polar Ionospheric Irregularities Experiment: Preliminary Results
AGU Mtg., San Francisco, CA (9-13 December 1985)

WHALEN, J.A.
Longitudinal Dependence of the High Latitude F-Layer Trough
AGU Mtg., San Francisco, CA (9-13 December 1985)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

ANDERSON, D.N. (AFGL); MENDILLO, M. and HERNITER, B. (Boston Univ., Boston, MA)
A Semi-Empirical Low-Latitude Ionospheric Model
AFGL-TR-85-0254 (10 October 1985), ADA168899

BAILEY, A.D., and SHERMAN, C.
EIRMA an Energetic Ion Retarding Mass Analyzer for the BERT-1 Beam Emission Rocket Test-One
AFGL-TR-86-0109 (19 May 1986), ADA178231

BASU, S. (AFGL); MACKENZIE, E., BASU, SUNANDA, COSTA, E. (Emmanuel Coll., Boston, MA); FOUGERE, P.F., CARLSON, H.C., and WHITNEY, H.E. (AFGL)
250 MHz/GHz Scintillation Parameters in the Equatorial, Polar and Auroral Environments
AFGL-TR-86-0070 (28 March 1986), ADA172211

DANDEKAR, B.S., and BUCHAU, J.
Improving foF2 Prediction for the Sunrise Transition Period
AFGL-TR-86-0028 (29 January 1986), ADA170457

DANIELL, R.E., STRICKLAND, D.J. (Computational Phys., Inc., Annandale, VA); DECKER, D.T. (Boston Coll.,

Newton, MA); JASPERSE, J.R., and CARLSON, H.C., JR. (AFGL)
Determination of Ionospheric Electron Density Profiles from Satellite UV Emission Measurements, FY-84
AFGL-TR-85-0099 (26 April 1985), ADA160368

HUNTON, D.E., TRZCINSKI, E., WLODYKA, L., FEDERICO, G., and DORIAN, J., 1LT
Quadrupole Ion/Neutral Mass Spectrometer for Space Shuttle Applications
AFGL-TR-86-0084 (7 April 1986), ADA172000

KLEIN, M.M.
A Parameterized Procedure for Determining Real Height from Ionograms by Use of Generalized Parabolic Profiles
AFGL-TR-85-0101 (8 May 1985), ADA160383

SHERMAN, C.
Collection of Ions in the Stratosphere
AFGL-TR-85-0317 (9 December 1985), ADA169905

WEBER, E.J., KLOBUCHAR, J.A., BUCHAU, J., CARLSON, H.C., JR. (AFGL); LIVINGSTON, R.C., DE LA BEAUJARDIERE, O., MCCREADY, M. (SRI International, Menlo Park, CA); MOORE, J.F., and BISHOP, G.J. (AFGL)
Structure and Dynamics of Polar Cap F-Layer Patches
AFGL-TR-86-0074 (31 March 1986), ADA175241

CONTRACTOR PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

BURCH, J.L., REIFF, P.H., MENIETTI, J.D., HEELIS, R.A., HANSOM, W.B., SHAWHAN, S.D., SHELLEY, E.G., SUGIURA, M., WEIMER, D.R., and WINNINGHAM, J.D. (Southwest Research Inst., San Antonio, TX)
IMF B_y-Dependent Plasma Flow and Birkeland Currents in the Dayside Magnetosphere. 1. Dynamics Explorer Observations
J. Geophys. Res. 90 (1 February 1985)

CREW, G.B. (Massachusetts Inst. of Tech., Cambridge, MA)
Generation of Lower Hybrid Waves by an Electron Beam of Finite Spatial Extent
Massachusetts Inst. of Tech. CSR-TR-85-24 (October 1985)

CREW, G.B., and CHANG, T.S. (Massachusetts Inst. of Tech., Cambridge, MA)
Asymptotic Theory of Ion Conic Distributions
Phys. of Fluids 28 (August 1985)

DE LA BEAUJARDIERE, O., WICKWAR, V.B., CAUDAL, G., HOLT, J.M., CRAVEN, J.D., FRANK, L.A., BRACE, L.H., EVANS, D.S., WINNINGHAM, J.D., and HEELIS, R.A. (Southwest Research Inst., San Antonio, TX)
Universal Time Dependence of Nighttime F Region Densities at High Latitudes
J. Geophys. Res. 90 (1 May 1985)

DHEANDHANOO, S., CHATTERJEE, B.K., and JOHNSEN, R. (Univ. of Pittsburgh, Pittsburgh, PA)
Rate Coefficients for the Oxidation Reactions of Zirconium Ions with Oxygen, Nitric Oxide, and Carbon Dioxide
J. Chem. Phys. 83 (1 October 1985)

KOSKINEN, H.E.J. (Massachusetts Inst. of Tech., Cambridge, MA)
Parametric Processes of Lower Hybrid Waves in Multicomponent Auroral Plasmas
AGU Monograph 38 (1986)

MENIETTI, J.D., WINNINGHAM, J.D., BURCH, J.L., PETERSON, W.K., WAITE, J.H., and WEIMER, D.R. (Southwest Research Inst., San Antonio, TX)
Enhanced Ion Outflows Measured by the DE 1 High Altitude Plasma
J. Geophys. Res. 90 (1 February 1985)

RODRIGUEZ, J.M., KO, M.K.W., and SZE, N.D. (Atmospheric and

Environmental Research, Inc. (AER), Cambridge, MA)
Possible Impact of Sodium Species on ClO and O in the Upper Stratosphere
Geophys. Res. Lett. 13 (June 1986)

ROSTOKER, G., KAMIDE, Y., and WINNINGHAM, J.D. (Southwest Research Inst., San Antonio, TX)
Energetic Particle Precipitation into the High-Latitude Ionosphere and the Auroral Electrojets. 2. Characteristics of Electron Precipitation into the Morning Sector Auroral Oval
J. Geophys. Res. 90 (1 August 1985)

SILVER, J.A. (Aerodyne Research, Inc., Billerica, MA)
Measurement of Atomic Sodium and Potassium Diffusion Coefficients
J. Chem. Phys. 81 (1 December 1984)

SILVER, J.A., STANTON, A.C., ZAHNISER, M.S., and KOLB, C.E. (Aerodyne Research, Inc., Billerica, MA)
Gas-Phase Reaction Rate of Sodium Hydroxide with Hydrochloric Acid
J. Phys. Chem. 88 (1984)

VVEDENSKY, D.D., ELDERFIELD, D.J. (Imperial Coll., London, England); and Chang, T.S. (Massachusetts Inst. of Tech., Cambridge, MA)
Critical Fluctuations Around Non- Equilibrium Steady States
J. Appl. Phys. 17 (1984)

WINNINGHAM, J.D., and BURCH, J.L. (Southwest Research Inst., San Antonio, TX)
Observations of Large Scale Ion Conic Generation with DE-1
Physics of Space Plasmas 5 (1982-1984)

CONTRACTOR TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

AKASOFU, S.I., and FRY, C.F. (Univ. of Alaska, Fairbanks, AK)
Development of a Geomagnetic Storm Pre-Prediction Scheme - Phase I
AFGL-TR-85-0152 (June 1985), ADA161651

BIONDI, M.A., and JOHNSEN, R. (Univ. of Pittsburgh, Pittsburgh, PA)
Atomic Collisions and Plasma Physics
AFGL-TR-86-0188 (31 August 1986), ADA175727

CHANG, T. (Massachusetts Inst. of Tech., Cambridge, MA)
Ionospheric Plasma Study
AFGL-TR-86-0206 (15 September 1986), ADA175695

DANIELL, R.E., JR., and STRICKLAND, D.J. (Beers Associates, Inc., Reston, VA)
Assessment of Methods for Monitoring the Ionosphere by Observing UV and Visible Emissions
AFGL-TR-85-0013 (January 1985), ADA165217

EATHER, R.H. (Keo Consultants, Brookline, MA)
Airborne Optical Systems
AFGL-TR-86-0133 (20 June 1986), ADA172173

ELGIN, J.B., and DUFF, J.W. (Spectral Sciences, Inc., Burlington, MA)
A Monte Carlo Description of the Sampling of Stratospheric Ion Clusters Via a Mass Spectrometer
AFGL-TR-85-0319 (October 1985), ADA168523

HAINES, D. M. (Univ. of Lowell, Lowell, MA)
Digisonde 256 RF Power Tests at Wallops Island - Test and Evaluation Report
AFGL-TR-86-0185 (August 1986), ADA173831

HARGREAVES, J.K., and BURNS, C.J. (Univ. of Lancaster, Lancaster, England)
EISCAT Electron Density Studies
AFGL-TR-85-0052 (29 January 1985), ADA152820

HILLS, R.S. (Tri-Con Assoc., Inc., Cambridge, MA)
Refurbishment of an Ultraviolet and Electronic Spectrometer and Photometer
AFGL-TR-85-0105 (29 April 1985), ADA160363

KERSLEY, L., and WHEADON, N.S. (Dept. of Physics, Penglais, Aberystwyth, U.K.)
Scintillation Using NNSS Satellites
AFGL-TR-85-0053 (31 January 1985), ADA152804

KINSEY, J.L. (Massachusetts Inst. of Tech., Cambridge, MA)
Laser Spectroscopy of Ozone
AFGL-TR-86-0006 (18 December 1985), ADA166516

KO, M.K.W., SZE, N.D., and RODRIGUEZ, J.M. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
A Research Program for the Neutral/Ion Chemistry of Metals in the Stratosphere and Mesosphere
AFGL-TR-86-0169 (30 July 1986), ADA175234

KUCZUN, C.G. (TRI-CON Assoc., Inc., Cambridge, MA)
Fabrication and Test of Modified Quadrupole Mass Spectrometer
AFGL-TR-85-0002 (10 January 1985), ADA155186

LEE, M.-C. (Regis Coll., Weston, MA)
Physics of Natural and HF-Induced Ionospheric Disturbances and Their Effects on Radio Communication
AFGL-TR-85-0163 (30 June 1985), ADA162159

LOWRANCE, J.L. (Princeton Scientific Instruments, Inc., Princeton, NJ)
Ultra Violet Imager System
AFGL-TR-86-0113 (15 April 1986), ADA172175

LUCAS, R.D., and ROBINS, R.E. (Physical Dynamics, Inc., Bellevue, WA)
Phase I Final Report: Implementation of an Ionospheric-Image File Management, Processing, and Display System
AFGL-TR-85-0082 (15 April 1985), ADA164502

MCNAMARA, L.F. (Univ. of Lowell, Lowell, MA)
Quality Control of True Height Profiles Obtained Automatically from Digital Ionograms
AFGL-TR-86-0098 (May 1986), ADA171328

MENDILLO, M., and HERNITER, B. (Boston Univ., Boston, MA)
A Model for the Low Latitude Ionosphere with Coefficients for Different Seasonal and Solar Cycle Conditions
AFGL-TR-86-0260 (1 November 1986), ADA178207

RODRIGUEZ, J.M., KO, M.K.W., and SZE, N.D. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
The Neutral/Ion Chemistry of Sodium in the Stratosphere and Mesosphere
AFGL-TR-85-0237 (30 September 1985), ADA164636

SALES, G.S., REINISCH, B.W., BIBL, K., and DOZOIS, C.G. (Univ. of Lowell, Lowell, MA)
Ionospheric Propagation Studies During the Precision Targeting Experiments
AFGL-TR-86-0030 (January 1986), ADA172316
Preliminary Investigation of Ionospheric Modification Using Oblique Incidence High Power HF Radio Waves
AFGL-TR-86-0203 (September 1986), ADA179174

SILVER, J.A., and KOLB, C.E. (Aerodyne Research, Inc., Billerica, MA)
A Study of the Chemistry of Alkali Metals in the Upper Atmosphere
AFGL-TR-85-0008 (January 1985), ADA156349

SILVER, J. A., and KOLB, C.E. (Aerodyne Research, Inc., Billerica, MA.)
A Study of Atmospheric Reactions of Neutral Sodium Species and Other Metals of Meteoric Origin
AFGL-TR-86-0010 (9 February 1986), ADA166561

SMITH, D., and ADAMS, N.G. (Univ. of Birmingham, Birmingham, England)
Ion and Electron Interactions of Atmospheric Importance
AFGL-TR-85-0247 (31 August 1985), ADA161619

SUKYS, R. (Northeastern Univ., Boston, MA)
Control and Signal Conditioning Circuits for E.I.R.M.A.
AFGL-TR-85-0117 (October 1984), ADA166683

SUKYS, R., and ROCHEFORT, J.S. (Northeastern Univ., Boston, MA)
Downrigger Instrumentation to Record Thermosonde Data
AFGL-TR-85-0085 (October 1983), ADA161748
Control Electronics for an Ion Mass Filter in the Lower Ionosphere Payload Development Program
AFGL-TR-86-0170 (30 September 1985), ADA175439

Dr. Arnold A. Barnes (right), chief of the Cloud Physics Branch, and TSgt Dennis L. Lagross, research and development technician, inspect the M-Meter, a device that measures the mass of raindrops. (The other instruments mounted beneath the wing of the airplane measure the size, shape, and number of particles in the melting zone of the atmosphere, 3,000-12,000 ft. In this layer, signals from Air Force microwave systems are absorbed, and communications at higher frequencies are impeded. The data from this Weather Attenuation Program will help develop methods to predict these losses.)

IV ATMOSPHERIC SCIENCES DIVISION

The Atmospheric Sciences Division investigates atmospheric effects on Air Force systems and operations. Present day military operations are at least as dependent upon the weather as at any time in the past. While some Air Force operations will be less affected by weather elements, newer operations will involve more complex and sophisticated systems that are weather-dependent. Thus the search for better methods of observing and predicting meteorological conditions continues to be a vital part of the geophysical research program of the Air Force.

During the period 1985-1986, projects in the Atmospheric Sciences Division have included: research on cloud and precipitation physics and numerical modeling and simulation of cloud physics; upper atmosphere specification; atmospheric dynamic modeling and mesoscale prediction techniques; improved techniques for automatic satellite-imagery analysis, research on obtaining water-vapor profiles from satellites, and the use of satellites in providing weather data within uncontrolled or enemy-controlled areas and airspace; climatological techniques for the design and operation of Air Force systems and development of prediction techniques for toxic chemical spills; and automated Doppler weather radar analyses and coherent polarization-diversity radar techniques.

CLOUD PHYSICS

During the past two years, the cloud physics program has emphasized cloud microphysics modeling along with efforts in field programs and instrumentation development. By incorporating knowledge gained in the field programs into the cloud microphysics models, we will obtain a more complete understanding of such microphysical processes as growth of ice crystals and snowflakes, melting of the snow in the free atmosphere, and the growth and evaporation of rain and cloud drops. We have begun to apply the model results to Air Force areas of interest such as electromagnetic attenuation, aircraft icing, nuclear winter, and scavenging of exhaust products deposited in the atmosphere by large rockets.

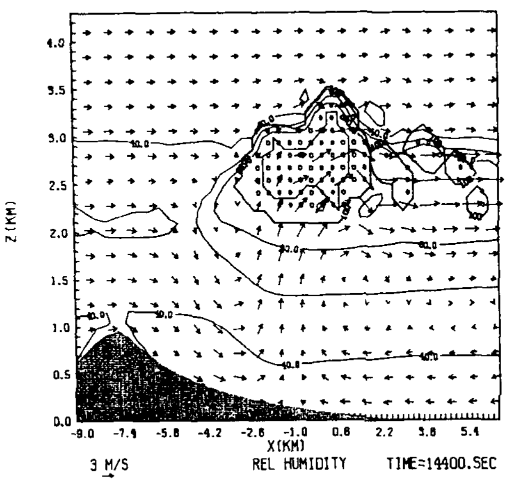
Cloud Microphysics Modeling: The purpose of this effort is to introduce more detailed microphysics into cloud models in order to provide more accurate simulated clouds for Air Force applications. Many Air Force weapon and communication systems are affected by processes such as microwave attenuation which occur within clouds and precipitation. Better understanding of the internal processes of clouds will enable engineers to design equipment which will operate more effectively in, and through, clouds and precipitation.

The AFGL Cloud and Mesoscale Model, a version of the cloud model developed at Colorado State University, is a two-dimensional or three-dimensional numerical model that runs on the Cray-1 computer at the Air Force Weapons Laboratory (AFWL) at Kirtland AFB, New Mexico. The model, which contains parameterized cloud microphysics, can be run with the microphysical routines deactivated to study dry atmospheric circulations, or with the microphysics activated to study complex cloud systems. The model has been run at AFGL to study thunderstorms, nuclear firestorms, and dry and moist mountain circulations.

A one-dimensional warm cumulus model with detailed microphysics, developed at AFGL some years ago to study the growth processes of droplets and the formation of rain in a simple convective environment, was reactivated and modified to include ice processes. The model now allows ice particles to form by either freezing of droplets or by nucleation, as well as growth by riming. The model has been used to study the nature of the development of rain and hail in mixed-phase cumulus clouds (those which contain both liquid water and ice particles) and the sensitivity of the particle-growth processes to the temperature and humidity environment.

Both models were applied to a well-studied Montana cumulonimbus cloud as a part of the International Cloud Modeling Workshop at Irsee, West Germany, sponsored by the World Meteorological Organization. The modeled clouds tested the sensitivity of the models to the concentrations of "cloud condensation nuclei," or CCN, which are related to the aerosol content of the air. When the model input included the appropriate CCN concentrations, both models predicted proper precipitation mechanisms in the cloud. In this regard, the models also agreed favorably with each other.

In response to a request from AFWL, we also ran the cloud and mesoscale model in three dimensions to simulate urban mass fires that would be ignited by nuclear explosions, according to the "nuclear winter" theory. These simulations showed that the height of penetration of the resulting smoke cloud was sensitive to atmospheric stability, atmospheric moisture, and the heat intensity of the fire. In addition to performing the modeling study, we attended several workshops on "nuclear winter" and briefed interested parties at AFWL on the "post nuclear strike environment."



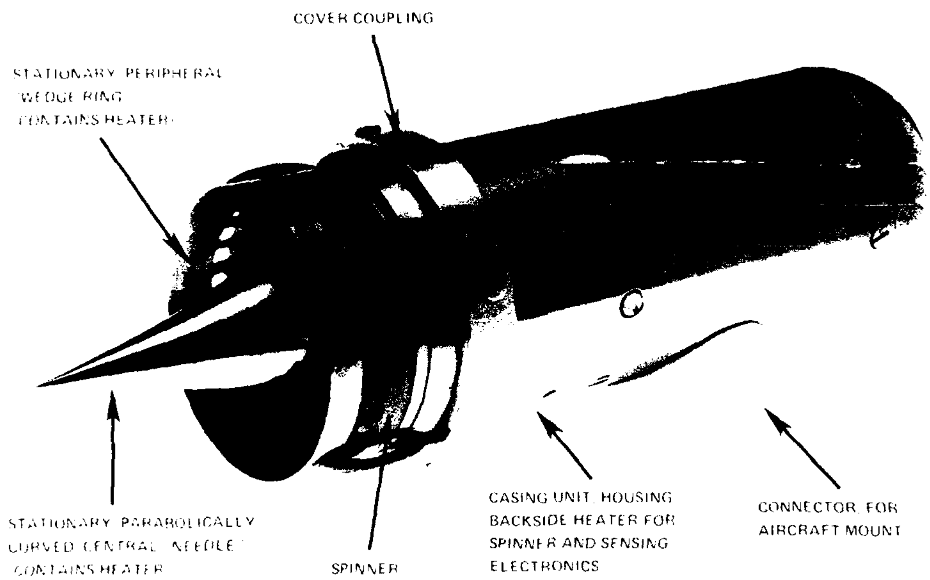
AFGL Cloud Model Output Showing Cumulus Clouds Developing from Mountain Circulations.

Mountain Thunderstorm Initiation: The forecasting of the location and timing of thunderstorms is an important operational problem in meteorology. Recent studies at AFGL have shown that forecasting thunderstorm initiation over mountainous terrain may be easier than over flatter land or ocean. Thunderstorms that begin over mountains are important because they can move out of the mountains to produce severe weather over neighboring lowlands, and storms generated in the Rocky Mountains, for example, can merge with other storms to become Mesoscale Convective Complexes. Often referred to as "MCC's," these extensive cloud systems are an important source of summertime rainfall in the central United States and they produce large areas of cloudiness which could affect Air Force operations (see the figure).

Studies with the AFGL Cloud and Mesoscale Model have shown that the lee side of mountain ranges is a fertile region for the initiation of thunderstorms, and that moisture, upper level winds, and the intensity of surface heating by the sun strongly control the ability of these regions to produce clouds. Further studies in the Cloud Physics Branch using geosynchronous satellite data to locate thunderstorm initiation sites have emphasized the significance of regions to the lee of mountain ranges as thunderstorm sources. These studies also showed that many isolated mountain peaks are prodigious producers of thunderstorms.

Instrumentation Development: Work efforts have continued on improving the quantitativity of our ground-based, cloud physics instruments, which have been designed to provide "measurement truth," in verification of AFGL cloud modeling and other efforts. These instruments include the rain and snow rate meters, the fall velocity indicator, the hydrometeor structure recorder, the volume recorder, and the ASCME liquid-water-content detector. All these instruments are designed to be as accurate and as fast-responding as the present state of the art permits.

Work has also continued on the M-meter, which is designed to measure the particulate mass content (also spectral content) of hydrometeors, dust, and atomic debris that might be present in the



M-meter Used to Determine the Specific Mass Constant of Atmospheric Hydrometeors and Other Particulates.

atmosphere (see the figure). This instrument is primarily an aircraft instrument but it can also provide data from the ground. A patent application for the instrument was filed in December, 1985. The instrument was flight-tested during the AFGL Weather Attenuation Program in the spring of 1986. Preliminary results from those tests indicate that the M-meter performed exceptionally well and that the instrument has the potential for becoming the standard instrument for atmospheric particle measurements.

Field Programs: Satellite communication systems operating at frequencies in excess of 20 GHz are subject to attenuation by precipitation. During the period of March 15 to May 22, 1986, the Cloud Physics Branch conducted a Weather Attenuation Field Program in the area around Hanscom AFB. The program included direct and indirect measurements of attenuation, airborne meteorological data from instrumented aircraft (operating under contract), and surface observations of drop size spectra and rainfall. Special loran sondes developed at AFGL were also used to obtain atmospheric soundings of temperature, humidity, and winds.

Attenuation measurements were obtained using three different methods: (1) Direct attenuation measurements at 38 GHz from satellite LES-8; (2) Indirect measurements from vertically pointing ground radars operating at 2 and 35 GHz; (3) Airborne K_a band radar data.

Airborne meteorological data provided in-situ measurements of liquid water content, particle-size distributions and shape, as well as temperature and humidity. The new M-meter, designed to measure the mass of ice and water, was also tested for collection of precipitation mass information in the melting layer.

In the attenuation program, measurements at the surface were made by the AFGL rainrate meter, a Joss disdrometer (which measures droplet size distribution), and a fall velocity indicator. Good data were acquired by all instruments on most operational days. Preliminary results of the data collection program reveal good correlation between the rainrate meter and the disdrometer. Also, on certain of the days there was evidence of correlation between the rainrate and the attenuation measured by Lincoln Laboratory from the satellite.

Approximately 40 flight hours of liquid water content data were obtained with the M-meter in the rain, melting layer, and snow regions of storms. Preliminary analyses of the data for one sortie (March 27, 1986) showed that the M-meter worked extremely well, although needed calibration data are still lacking.

Measurement Support: A measurement support program has been conducted beginning in the summer of 1986 and continuing. In this program AFGL rain and snow instruments have been operated at Otis AFB to provide "ground truth" measurements in support of the Division's Automated Observations Task, the Air Weather Service, the National Weather Service, and the FAA.

UPPER ATMOSPHERE SPECIFICATION

Many Air Force systems operate in or through the upper atmosphere. These systems include high-altitude reconnaissance aircraft, missiles, military satellites, optical and infrared surveillance systems, radars and communications. These systems, in addition to a number of technologies and systems in Project Forecast II, such as Hypersonic Aerothermodynamics and Hypersonic Vehicles and Weapons, critically need precise specification of upper atmosphere properties for systems to be efficiently designed and effectively operated. This requires investigating the phenomenology and developing climatologies and empirical and theoretical models. The climatologies and models must provide mean values as functions of the appropriate parameters, such as latitude, longitude, time of year, and solar flux. It is also necessary to provide ranges of variability about the mean values.

Models and Data: The Proceedings of the Workshop on Middle and Upper Atmosphere Models and Data (held as part of the COSPAR Meeting at Graz, Austria, in July, 1984) were edited and published in 1985 as part of a volume in the journal *Advances in Space Research*, entitled "Models of the Atmosphere and Ionosphere." The volume contains data and empirical models of the middle atmosphere and thermosphere and theoretical thermosphere models. The properties include temperature and winds from meteorological rockets and radar systems, and from satellite remote sounding; density from satellite drag data; and composition from balloon, rocket and satellite remote-sounding data. Three-dimensional, time-dependent theoretical thermosphere models have been developed by numerically solving the energy and momentum equations to produce a global representation of the structure and dynamics of the thermosphere. These are upper-atmosphere general circulation models and include energy inputs from solar ultraviolet and extreme ultraviolet emissions, and energy and momentum inputs from the solar wind.

A new set of models developed by AFGL contractor Groves was published as "A Global Reference Atmosphere from 18 to 80 km". The models were derived using satellite remote-sounding temperature data and rawinsonde and rocket data. They present structure properties as functions of latitude, longitude, and time of year and constitute the first set of reference atmospheres for this altitude region with distinct models for the northern and southern hemispheres. Since that time, Groves has extended these models in altitude to 130 km, where they merge with a set of thermospheric models, MSIS 83 (Mass Spectrometer and Incoherent Scatter), developed by NASA Goddard Space Flight Center.

Thermospheric Density Variability: Persisting deficiencies in understanding lower thermosphere neutral density and wind variations continue to impact Air Force operations that require knowledge of aerodynamic drag effects on space-vehicle trajectories. These requirements include design and operation of the National Aerospace Plane, satellite tracking and reentry predictions by Space Command, and the control and operation of DoD mission satellites by Space Division's Air Force Satellite Control Facility. There is a particularly critical need for better models in the 90-200 km region. Data are relatively sparse at altitudes above those reached by most rockets and below those reached by most satellites. To provide users with state-of-the-art understanding of this region, the Air Force Reference Atmospheres, 1978, have been extended to 200 km from their previous upper boundary of 90 km.

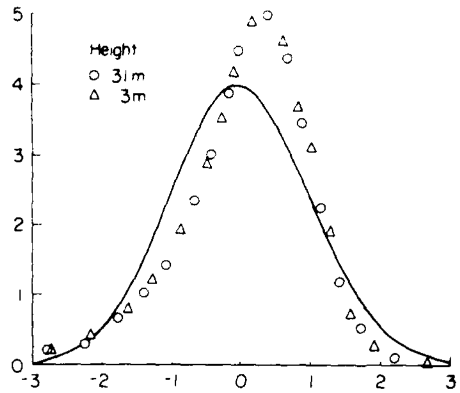
Temperature measurements from rocket experiments and ground-based incoherent scatter radars formed the basis for the 90-104 km region of the forthcoming Air Force Reference Atmosphere Supplements. Zonally averaged values of temperature, density, and pressure were derived as functions of altitude, latitude, and month for the northern hemisphere. From 120-200 km, the MSIS 1983 (Mass Spectrometer and Incoherent Scatter) models were adopted. These models are a function of altitude, latitude, day of year, local time, solar flux and geomagnetic activity Between 104 and 120 km, the two sets of models were merged such that the MSIS variations due to local time and solar and geomagnetic activity decreased from their appropriate values at 120 km to zero at 104 km.

The models also provide information on climatological variations in density. Below 120 km, available measurements and theoretical interpretations were combined to estimate variability due to tides and gravity waves. Above 150 km, variability was determined from AFGL satellite accelerometer-drag measurements. Our results provide the most extensive database of density at low satellite altitudes. Data from nine flights were used to statistically evaluate the atmospheric variability representations in twelve empirical models. Results showed that models typically had a globally averaged one sigma standard deviation of 15 percent, with larger errors occurring at high latitudes and at higher geomagnetic activity. The study showed a lack of significant progress in density-model accuracy improvements over the past two decades. Our analyses also revealed errors in model mean values as functions of latitude, season, and local time. For example, density values measured at low-to-middle latitudes near 190 km at 2200 hrs with the sun-synchronous S85-1 satellite were 20-30 percent higher than model predictions. These nighttime densities generally exceeded those measured at 1000 hours at the same altitude and latitude.

The inability of empirical models to achieve improved accuracy has led to initiation of a new approach for forecasting density variability, involving incorporation of new physical concepts and parameterizations of dynamics into models. The basis for these improvements are general circulation models that consider thermospheric, dynamic, energetic, and chemical processes as part of the coupling between the magnetosphere, ionosphere, and neutral atmosphere. A detailed geomagnetic storm simulation case study was carried out to compare general circulation and empirical model predictions with accelerometer density and winds measurements. The circulation models were more accurate and gave higher resolution descriptions of density variability and realistic specification of winds, which are not included in empirical models. Understanding of wind motions is important not only for theoretical knowledge of dynamics, but because velocities of 1 km per second, sometimes observed at high latitudes under storm conditions, can perturb drag because of density fluctuations by up to ±25 percent. Our study has demonstrated the feasibility of using dynamic models to develop a more accurate density and drag forecasting capability.

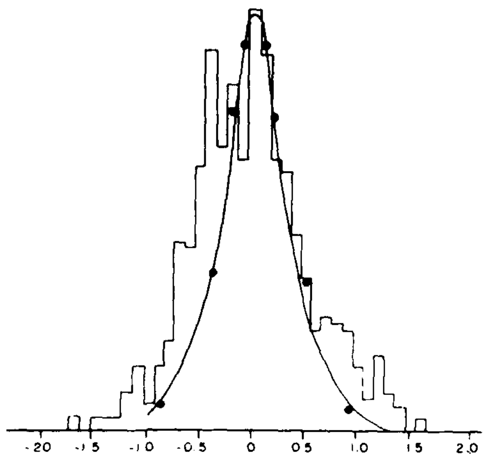
With Laboratory Director's Funds, the feasibility of measuring atmospheric density in the upper mesosphere and lower thermosphere by using passive satellite remote-sensing techniques will be evaluated. This study will evaluate the accuracy with which density can be obtained; the cost, weight, and power of the instrumentation required; and the complexity of the data analysis. The tradeoff study will provide the basis for consideration of a remote-sensing system capable of monitoring global density in the 80-150 km altitude region. Such a technique, if successful, could provide global density data in an altitude region where measurements presently consist of only a few rocket flights.

Upper Atmosphere Turbulence: An important part of the Energy Budget Campaign held in northern Europe during November and December, 1980, was the rocketborne BUGATTI (Bonn University Gas Analyzer for Turbulence and Turbopause Investigations) mass spectrometer measurement of the N_2 and Ar number densities. This instrument has a spatial resolution approaching 20 meters, which permitted, for the first time, measurements of fine-scale turbulence down to scale sizes of a few mean free paths. Measurements were made under quiet conditions and during a moderate geomagnetic storm. The turbulence power spectra were obtained as a function of altitude between 69 km and 115 km. The measurements during quiet conditions show the usual inertial, or Kolmogoroff, $k^{-5/3}$ power spectrum (where k is the wave number) up to about 110 km, which appears to be the turbopause altitude, and a flat noise-like spectrum above that altitude. This spectrum may be generated by the instrument. The data obtained under moderately disturbed conditions show the Kolmogoroff-type spectrum up to about 95 km and the flat noise-like spectrum at higher altitudes.

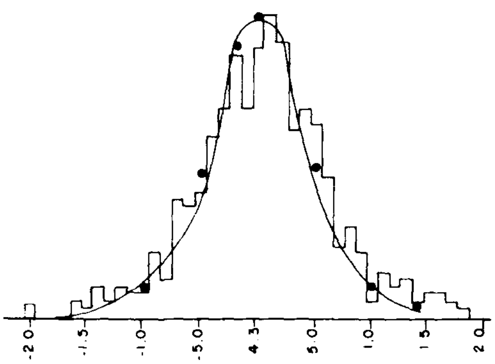


Occurrences of Turbulent Temperature Fluctuations in Boundary Layer Measurements. (The skewed Gaussian distribution due to turbulence is very apparent.)

These spectra might suggest the cessation of turbulence above 95 km but plots of the argon/N_2 density ratio do not confirm this. (Because of the mass ratio 40/28 the argon/N_2 ratio decreases rapidly at altitudes above where turbulence mixing exists.) The argon/N_2 ratio dips above 105 km but increases again to 114 km, with a second dip and recovery near 118 km. These data can either be due to an instrument artifact or suggest a source of mixing in these altitude regions. To obtain additional information on this phenomenon, the statistics of occurrence of the fluctuations were investigated (see the figure). The distribution in the figure for



Occurrences of Rocketborne Nitrogen Density Fluctuations Measured at 90 to 100 km. (These data follow the skewness distribution in the inverse sense of the preceding figure.)



Occurrences of Density Fluctuations for the 110 km to 120 km Region. (Note the close comparison of the measured data with the nomalized Gaussian curve, indicating a noise-like mechanism as the generating mechanism.)

the altitude region 90 to 110 km is skewed relative to a Gaussian distribution. This distribution is similar (except reversed as expected) to that in the preceding figure obtained by Chen by analyzing boundary-layer temperature fluctuations. On the other hand, the figure for the altitude region 110 to 120 km shows a Gaussian or noise-like spectrum. This can be interpreted as due to instrument noise or due to a different mixing mechanism. Since this result was obtained under moderately disturbed conditions, it may be due to additional atmospheric heating resulting from particle precipitation, or from enhanced electron heating due to increased electric currents or fields.

Analysis of turbulence intensity determined from Meteorological Rocket Network (MRN) data demonstrates that the northern latitude (Poker Flat, Alaska, latitude 70°N) winters are much more energetic than the summers, and show a higher occurrence rate of turbulence. The Wallops Island results of diffusivities (K_H) also show this winter-summer trend as does Cape Kennedy, but the Fort Sherman (Canal Zone) results indicate a reversal of these dynamics, where the summer turbulence is more intense than that of the winter.

When considering the diffusivities (K_H) we observe the intense variability of the northern latitude (Thule) winter, and the more uniform behavior of the summer season. This is similar to the results of the rocket grenade data but, because of the finer scale of the measurement grid, we have turbulence measurements to lower altitudes for both winter and summer. This is particularly true for the lower latitudes, where the data show an almost continuous profile down to approximately 35 km. The Wallops data near 30 km show a ledge of amplitude diffusivity. This phenomenon was noted by Zimmerman and Keneshea. These large amplitude energetics are also noted in the turbulent wind acceleration and total heat production and loss mechanisms. Moreover, at Cape Kennedy, we also observe significant winter heating at the lower altitudes, and again in the summer. There is a suggestion in these energies that they must be related to a mid-latitude source constrained in the upper stratosphere, perhaps the "jet stream" that migrates around the mid latitudes.

The turbulence wind acceleration is generally balanced, positively and negatively, except for the winter at Cape Kennedy, where turbulence provides an effective drag on the wind system, and at Fort Sherman in the summer, where there is a large net acceleration to the mean winds. The total turbulence heating shows a general balance of heat production and loss in the mid and northern latitudes, but at Cape Kennedy and Fort Sherman for the winter, and around 60 to 70 km, there appears to be a significant loss of heat. In the summer, however, at Fort Sherman, turbulence is depositing significant heat into the mesosphere to the value 3×10^{-3} K per second or 300°K per day.

Specification of Atmospheric Properties: An important activity has been to determine Air Weather Service (AWS) requirements for inputs of improved scientific models and data so that AWS can provide better weather-related data to users. To this end working group meetings have been held both at AFGL and at Air Force Global Weather Central (AFGWC). Some of the properties for which improved specification is required are: surface weather history, visibility, aerosols, optical transmission, and structure properties from the surface to the lower thermosphere. The AFGL Optical Physics Division has provided the latest upper atmosphere models.

A study was performed on methods of meteorological data specification and analysis. The emphasis for the former was on retrieval of data from satellite-borne sensors. Properties included cloud cover, temperature, visibility, fog, moisture, precipitation, and snow cover. Methods of statistical interpolation were investigated as a means of obtaining objective analyses of meteorological data fields.

The Strategic Air Command, the Ballistic Missile Office, the Naval Surface Weapons Center, and the United Kingdom are all interested in weather effects on reentering missiles. Working group and technical interchange meetings have been held with representatives of these organizations. Density and winds affect the targeting accuracy of missiles. Under most conditions the effect maximizes in the stratosphere. Clouds and precipitation, hydrometeors of all kinds, affect reentering vehicles. Climatology of cloud types, heights, and frequency of distribution and climatology of precipitation type, rates, and distribution are of interest, as well as the potential for detailed information of this type from satellite remote-sounding instruments.

ATMOSPHERIC PREDICTION

Basic research studies in atmospheric prediction have concentrated on improving the representation of moist physical processes in global and regional scale atmospheric models. Concurrently, exploratory development programs have focused on the development and evaluation of global and regional layered cloud-forecast techniques and computer-compatible mesoscale techniques and models which will provide point and area forecasts of surface wind and sensible weather (clouds, visibility, precipitation) for time periods out to 12 hours. Techniques and models under development are expected to have the potential of operational application in the Air Weather Service (AWS) at either the Global Weather Central (AFGWC) or at the nearly 200 base weather stations which AWS mans around the world. Consideration is given to the capabilities and/or limitations of current and future systems in the formulation of models (techniques). Other studies examine the benefits that could accrue to operations if the system capabilities were expanded beyond present operational limits, particularly as regards additional data sources.

Global Dynamic Modeling: Much of the progress attained during the past two to three decades in weather forecasting accuracy can be attributed to advances in numerical simulation models of broad-scale weather circulation patterns. The accuracy of the numerical models depends on three factors: (1) the accuracy or completeness of the physical laws governing atmospheric interactions, (2) the accuracy with which the mathematical statements expressing the physical laws are carried out computationally, and (3) the adequacy of databases used to initialize the models. The global numerical weather prediction (NWP) program at AFGL uses a research-grade spectral model of the global atmosphere which follows closely the structure of many other multi-layer spectral models. With global spectral models (GSM), horizontal variations are represented by values in discrete layers. The basic equation set includes the equations of motion in sigma coordinates, momentum (represented by absolute vorticity and divergence), continuity, and hydrostatic and thermodynamic equations (the last two in forms suited to Arakawa vertical differencing).

Certain subgrid-scale physical processes must be accommodated within larger scale numerical simulation models through procedures known as parameterization. In establishing a baseline model at AFGL, we adopted the global spectral model implemented operationally at AFGWC as a point of departure. The parameterized physical processes in it fall into three broad categories: boundary layer processes; moisture physics, including convective adjustment and large-scale saturation effects; and subgrid-scale diffusion.

Research and development with the GSM involves a substantial amount of computer simulation running with large, global data-bases. Two computer systems are being used for these purposes: (1) a CYBER 860 at AFGL for the preliminary testing of new procedures in the model's software and for the analysis and evaluation, after the fact, of model performance data and (2) a CRAY-1 computer at the Air Force Weapons Laboratory for the actual model simulation experiments. Two five-day periods that are part of the First Global GARP Experiment (FGGE) database are being used to test the performance of the GSM in generating predictions of geopotential height, wind, temperature, and water vapor for time periods out to 96 hours.

FGGE was designated as a period of intense international cooperation in 1979 during which atmospheric and oceanographic observational field programs were undertaken to provide a "state-of-the-science" database of operational and research-grade measurements to support a wide-range of global and regional research and development purposes. The FGGE database has become the basis for major numerical weather prediction (NWP) modeling research and development efforts world-wide. For studies concentrating on cloud and moisture processes and prediction globally, it is particularly ideal when augmented by the highly-detailed 3D cloud (neph) analysis fields of AFGWC.

Earlier studies with the baseline GSM had demonstrated that moisture forecasts are the least skillful aspect of the model, exhibiting only minimal skill at all forecast intervals from 12 to 96 hours. This problem was attributed, in part, to the poor quality of the analyzed FGGE moisture fields, to the moisture physics parameterization schemes, and/or to the vertical advection and interpolation schemes for the model's moisture variable, specific humidity.

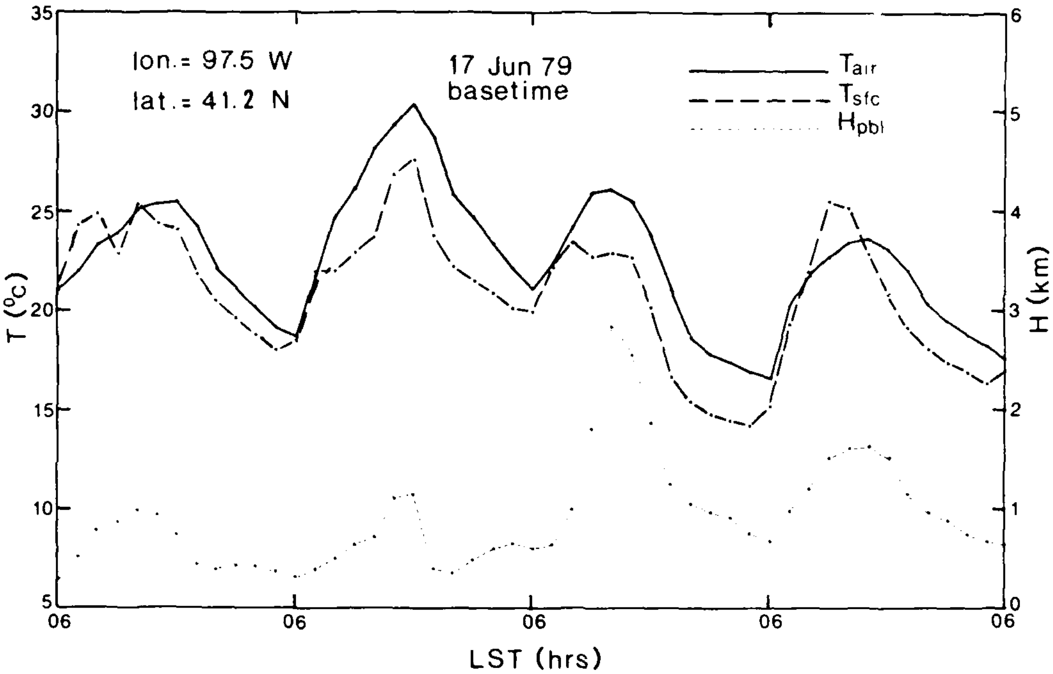
Objective Analysis and Data Assimilation: The accurate global depiction of atmospheric variables (height, wind, temperature, humidity, and clouds) is crucial to the initialization of global NWP models. During the period of this report, particular attention has been paid to the objective procedures used to first analyze and then assimilate humidity information. To that end, five-day experiments were conducted to assess the impact of alternative sources of humidity information on the accuracy of global relative humidity analyses. The sources considered were: satellite moisture retrievals, surface weather observations, and the AFGWC 3-D nephanalyses (cloud amounts). Collocation studies were conducted to compare each of their estimates of humidity with radiosonde values. While humidities inferred from surface weather observations and the 3-D nephanalyses were found to agree well, the TOVS moisture retrievals were not and were excluded from further study. Subsequent inclusion in the global analyses demonstrated that the 3-D nephanalyses in particular had a beneficial impact on the analyses at all levels from 1000 to 300 mb.

The AFGL GSM with very simplified physics representations was then subjected to a series of 48-hour simulation experiments after being initialized with different humidity fields. Without convective adjustment, the model was found to be largely insensitive to the specification of initial humidity. A GSM with convective adjustment resulted in better forecasts when an analysis based on 3-D nephanalysis and radiosonde humidity observations was used to initialize the model. The relative insensitivity of the forecast model to variations in initialized humidity fields points to the need to enhance moist physical parameterizations in the model in conjunction with the enhanced humidity analyses.

Planetary Boundary Layer Processes: For simplicity, most global circulation models neglect the influence of surface moisture flux over land because they are mainly concerned with the prediction of mass and motion fields and, perhaps, precipitation. In the quest for global models tailored for moisture and cloud forecasting, surface moisture flux can have important influences on the diurnal development of the planetary boundary layer, related low cloud fields, and mass and motion patterns in general. Considerable research has been concentrated, therefore, on the development of models for stability-dependent potential evaporation, for soil hydrology, for potential evaporation, for transpiration, and the canopy water budget in the atmospheric boundary layer. In accounting for surface heat and moisture fluxes over land, snow, and ice (as well as over water, as is commonly done in operational models), the boundary layer model (BLM) includes a diurnal cycle and a surface energy budget calculation. It has been structured to account for surface albedo, soil type, snow/ice characteristics, and vegetation type. As such, it explicitly predicts hour-by-hour the depth of the boundary layer, the ground surface (or skin) temperature, air temperature just above the ground, soil temperature and moisture, and boundary layer winds, stability, and cloud amount.

In order to accommodate the additional features represented by the new boundary layer procedure, the AFGL GSM was restructured vertically to provide greater resolution in the lower troposphere. Increasing the vertical layering in the boundary layer meant decreased layering in the stratospheric region in order to retain a structure with a total of twelve layers. Forecast simulation experiments were conducted with the 1979 FGGE data sets substituting the new BLM for the version in the operational model. The figure illustrates the dynamic response of the global prediction model to the new BLM at one particular geographic location (near Omaha, Nebraska) over a four-day period. Particularly noteworthy is the ability to replicate the diurnal variation of the depth of the boundary layer which is typically shallow at night and, as illustrated here, can be several kilometers thick on some days and less so on others depending on broader scale environmental conditions.

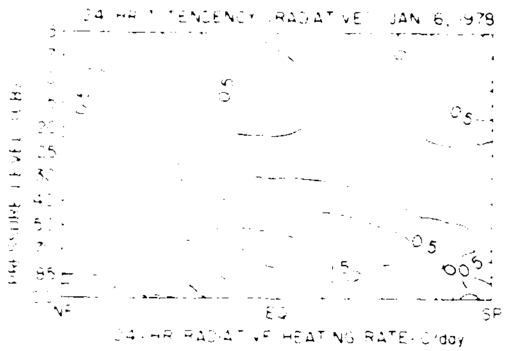
Cloud-Radiation Interactions: Another factor neglected in many global circulation models, but one that has greater importance when the model's purpose is moisture and cloud forecasts, is radiation effects. A broadband emissivity and absorptivity approach was used to develop a



Diurnal Variation over Local Standard Time (LST) of Ground Surface Temperature (Tsfc), Lowest/Atmospheric Layer Temperature (Tair at ~40m), and Boundary Layer Depth (Hpbl) at a Given Grid Point in a 4-day Forecast of the AFGL Global Spectral Model with the OSU PBL Model Included.

computationally reasonable parameterization model to account for the transfer of thermal, infrared, and solar radiation in clear and cloudy atmospheres. The emissivity for the individual absorption bands was derived either from band models (water vapor and ozone) or line-by-line data (carbon dioxide). High clouds in the atmosphere were treated as non-black and their emissivity, transmissivity, and reflectivity were parameterized in terms of their vertical ice content. Solar radiation was accounted for by developing broad-band absorptivity for water vapor, carbon dioxide, and ozone. Cloud reflection and transmission properties were parameterized in terms of liquid water content and solar zenith angle. These properties were then used to compute upward and downward radiative fluxes for clear and cloudy atmospheres having one or two layers.

The principal impact that properly accounting for the effects of solar and terrestrial radiation has in a GSM is net radiative cooling in the troposphere (particularly in the tropics) and slight heating in the tropical stratosphere. This is illustrated in the figure, which depicts the zonally-averaged 24-hour radiative temperature tendency from pole-to-pole based on two model simulations, one accounting for cloud-radiation effects and the other not. In nature (and hopefully in a numerical simulation model) the net cooling ef-



Zonally Averaged 24-hour Radiative Temperature Tendency Difference Field: Global Spectral Model (GSM) with Effects of Radiation Included Minus GSM Simulation without Effects of Radiation Included (Dashed isopleths represent regions of net radiative cooling and solid isopleths, regions of net radiative heating.)

fects of radiative processes are offset or balanced by heating due to exchange processes in the boundary layer and convective cloud processes. Thus, adding procedures in the model to account for net radiative cooling has to be complemented by appropriate modifications to the other components as well. It is in this area that research with the AFGL GSM is presently being conducted.

Moist physical processes in the atmosphere typically occur on spatial scales smaller than the scale that can be resolved by a global prediction model. Thus their effects are simulated via a parameterization process that seeks to account for the sub-grid scale events on the spatial scale of the model. The third area that such research has been focusing on is the treatment of cumulus convection where the effects of condensation, evaporation, and the vertical transport of heat and moisture by cumulus clouds is accounted for on the model grid. The objective of the modifications made to the existing procedures was to design a procedure better suited to cloud and moisture prediction and less focused on convective precipitation. To that end, an alternative partitioning of calculation of the vertical (convective) advection, of potential temperature (heat), and specific humidity was developed. In addition, the procedure now incorporates the explicit calculation of the convective cloud top height based on convective strength and environmental stability and more completely accounts for the effects of dry air entrainment on the cloud's heating and moistening profiles.

Here, again, global forecast simulations have been run using the 1979 FGGE data sets. In comparing model runs with the new cumulus convection procedure, there is a noticeable increase in the globally-averaged convective precipitation rate during the first 12 hours of the simulation. During the remaining 84 hours of the 96-hour simulation, the model tends to systematically dry out (produce less and less precipitation). However, when the new boundary layer procedure and the cloud-radiation procedure are also added to the model, the increased precipitation generation is maintained throughout the simulation period. While the research program is in its very earliest stage of testing the integrated effect of the new moist physics procedures, and the results and conclusions reached must be viewed as preliminary, there are clearly positive and complementary attributes added to the AFGL GSM with the new physics routines. The more extensive boundary layer treatment to include exchange processes over land and snow/ice areas, as well as over ocean areas, is providing a means of transporting heat and moisture into the lower troposphere where convective processes can, where appropriate, distribute them vertically through an environment in which the effects of radiative heating and cooling processes are being accounted for.

Regional NWP Models: The operational Air Force requires cloud forecasts on horizontal scales (50-100 km) that can only be obtained, computationally, through the use of limited-area or regional NWP models. Because there has been substantial interest internationally in forecasting mass, motion, and precipitation on these scales, there is ample evidence that regional models can indeed deliver useful and more detailed forecasts of these variables out to 48-60 hours. Here, again, the main USAF interest is for cloud and moisture forecasts, where little emphasis has been placed up to now.

We undertook the development of a research-grade relocatable limited-area NWP model (called RLAM), structured in a flexible modular fashion to accommodate testing and experimentation. As with the GSM, the principal research and development focus will be on the impact of alternative moist physics processes on model performance. In view of the likely sensitivity of the cloud and moisture forecasts to numerical and dynamic factors, as well as moist physics, a modular structure has also been used for those aspects. The RLAM would, in an operational forecasting setting, be executed in a nested framework using initial and boundary conditions from a GSM. Two or more options exist for solving each of the following components of the RLAM: vertical discretization, horizontal discretization, time integration, lateral boundary conditions and filtering. The initial version of the model contains separate routines to activate a simple moist convection scheme, a dry convective adjustment, and a simple boundary layer flux of momentum and temperature over water.

Tests of various versions of RLAM thus far have involved intercomparisons with the predicted fields of an operational regional model and the GSM. This testing has uncovered a number of computational issues related to model execution time and the extent to which smoothing procedures have to be applied in order to maintain numerical stability in the model simulation. The current physics routines have been found to produce boundary layer fluxes, moist convection, and precipitation in reasonable agreement with the operational regional model's fields. With the establishment of a functioning RLAM, a series of experiments is being prepared which will lead to the test and evaluation of the impact of the advanced physics routines (described earlier in the discussion on global dynamic modeling).

Mesoscale NWP Models: A research program is underway to develop generic mesoscale NWP models for cloud and precipitation forecasting applications at both AFGWC and in base weather stations. The basis of these studies is a three-dimensional hydrostatic, moist primitive equation model which, in its first form for testing, was initialized with a single radiosonde and modified by underlying terrain variation. The model structure consists of 16 terrain-following surfaces and a square domain spanning 500 km with a grid resolution of 20 km. Initial testing of the model using special data collections in central Texas during NASA's AVE-VAS program revealed a number of model weaknesses. These problems appeared to stem from the initialization, the lateral boundary conditions, and the treatment of surface energy-budget terms. An alternative to the single-sounding initialization approach was studied wherein a network of relatively dense surface observations was used in conjunction with the single sounding to initialize model fields through the boundary layer. While this simple blending approach yielded improvements for potential temperature and mixing ratio, the initialized wind fields were, in fact, degraded. Research is presently focusing on refinements to this approach to resolve, in particular, the inherent weaknesses that exist.

Regarding lateral boundary conditions, three alternative treatments are being evaluated for meso-beta scale models of the type being used. The alternatives are: a combination of fixed pressure and thermodynamic boundaries and extrapolated velocity boundaries, a sponge boundary which absorbs waves by reducing their phase speed as they approach the boundary, and radiation-type boundaries which seek to allow unwanted wave disturbances to propagate out of the model domain with no reflection at the boundary. Both one-dimensional and three-dimensional model simulations have been used to evaluate the alternatives. Analytical one-dimensional shallow water models provide a fast, computationally efficient means to initially test ways to incorporate global forcing in lateral boundary-condition formulations. The testing with 3-D models completed thus far has used a dry, hydrostatic model and has focused primarily on multi-dimensional (1-, 2- and 3-D) radiation conditions. Numerical instabilities related to the vertical component of wave-phase speed and complications due to unrealistic depletion of mass in the model integrations have limited the extent to which a selection of the preferred boundary condition for meso-beta scale NWP models can be made.

Lastly, research is concentrating on the formulation of methods of accounting for diurnal variations of ground surface temperature in order to more properly model the fluxes of energy from the surface into the boundary layer of a mesoscale NWP model. To this end, a soil-slab model has been formulated using the so-called force-restore method. It explicitly specifies the diurnal variation of ground surface temperature which in turn drives the calculation of soil heat flux. The framework of the soil-slab model allows numerical sensitivity tests of relevant physical process; e.g., the response of surface-temperature amplitude and phase to moisture availability, surface roughness, and thermal capacity.

Mesoscale Prediction Techniques: Improvements in mesoscale (or short-range) weather prediction can be tied to a more complete description of the atmosphere at observation time and changes in its recent past. The extent of spatial and temporal detail incorporated into this capability, generally referred to as "nowcasting," is largely dependent on the basic data sources used in the analysis. At this point of technology development, the potential of combining conventional surface and radiosonde observations with digital satellite (imagery and sounding) and radar imagery (Doppler and conventional) offers promise of substantial improvement in our ability to more completely describe the state of the atmosphere (nowcast). That potential is greatest in mesoscale meteorology with geosynchronous satellite (GOES-type) data (which provides practically continuous views of the same geographical area at half-hour intervals), with the use of minicomputer-based interactive graphics systems, and with the viable emergence of meso- and cloud-scale NWP models.

The products of the nowcasting studies are computer-generated descriptions of the state of the atmosphere derived from successively more complete data sets. They provide the basic input to short-range (mesoscale) prediction models. Models must be tailored to: (1) the limitations of the nowcast data sets, (2) the forecast range of interest, (3) varying levels of sophistication in the treatment of the physics of the prediction problem, and (4) limited computer capacities. The principal determinant for the approach taken for a particular forecast model is forecast range. For the very short-range prediction (0 to 6 hours), fairly simple extrapolation/translation models are most appropriate because more complete numerical models can never be expected to be executed operationally in a timely enough manner to be useful.

The main constraint placed on these development efforts relates to their potential application within planned AWS mini-computer systems with or without an interactive graphics capability. This means that the techniques under consideration are either objective (completely computer-generated) or interactive (assume a trained forecaster using computerized procedures to assist in the prediction solution). The goal, again, is to develop models for point and area forecasts of winds and sensible weather for time periods out to 12 hours.

Expert Systems: The science of short-range weather forecasting is based, to a very large extent, on the diagnostic and interpretive skills of professional meteorologists. The process through which they assimilate fragmented pieces of data on complex and evolving weather systems is itself complex and molded through experience. It is based on known physics principles, supplemented by a pragmatic knowledge of the complex interrelationships understood to exist in the atmosphere in space and time and fine-tuned through an experience-data-base structured in one form or another on forecasting rules or guidelines acquired on one's own or learned from others. In principle, then, the problems in short-range weather forecasting may be amenable to exploitation by artificial intelligence or expert system computer methods.

Short-range (0 to 6 hour) forecasting of in-theatre conditions can depend heavily on the effective gathering, interpretation, and application of environmental information. The volume of data potentially available to the operational forecaster through modernized computer-based weather support systems coming into the AWS inventory within the next 5-10 years presents a human information processing challenge of substantial proportions. Two studies were undertaken to evaluate the potential of artificial intelligence, or expert system, approaches to aiding weather forecasters in effectively evaluating short-range forecast problems in a timely manner.

In one study a prototype expert system for the classical single-station weather forecasting problem was developed. The skills required to maximize forecast quality based on such limited data are being lost because of the growing sophistication of numerical weather prediction models, statistical forecasting methods, and data assimilation/communication systems. However, single-station forecasting skills continue to have applications in (1) military scenarios involving remote locations that may encounter communications interruptions; (2) improving local short-range forecasting, both in terms of forecast quality and forecaster skills; and (3) providing station data interpretation as a part of a much larger meteorological expert system that would accept input from numerical models, radar, satellites, and other sensors. Protocol for the expert system was collected by having a meteorologist experienced in single-station forecasting prepare forecasts for a number of case studies from archived data. The prototype used an expert system building shell which allows the use of forward and backward chaining rules, frames, and other functions and procedures which can be written in LISP. The initial prototype performed as an experienced meteorologist's assistant and included an extensive use of graphics.

The second study focused on the prediction of low visibility due to fog at three military bases in the mid-Atlantic region (Dover AFB, DE; Seymour Johnson AFB, NC; and Fort Bragg, NC). Separate rule-based expert systems were developed for each location based on synoptic and subsynoptic reasoning, guidelines available in local forecast studies, and by interviewing experienced weather forecasters at the bases. The rules were organized into a decision-tree type of structure, augmented by evaluating historical low-visibility events and evaluated via a two-month system utilization phase in each of the identified USAF base weather stations. Based on the results of the two feasibility studies, it can be concluded that short-range weather forecasting is an area where the attributes of expert systems can be utilized operationally, following more rigorous and extensive development efforts.

SATELLITE METEOROLOGY

The performance of many Air Force systems can be strongly affected by the geophysical environment. For this reason, investi[illegible]ns into improving methods of observing and predicting meteorological conditions continue to be a significant element of the research program carried out by AFGL. Research in satellite meteorology is focused on a broad range of remote-sensing areas in an effort to provide the Air Force with ever-improving capabilities of acquiring and analyzing real-time environmental satellite data.

Projects in satellite meteorology include improved satellite image-processing techniques for the automated analysis of clouds, the investigation of infrared and microwave spectral regions for retrieving atmospheric temperature and water vapor profiles, and the assessment of incorporating satellite data to provide moisture parameters for numerical weather prediction (NWP) models. Most of the data for these studies comes from the primary sensors onboard meteorological satellites, including polar-orbiting Defense Meteorological Satellite program (DMSP) and National Oceanic and Atmospheric Administration (NOAA) spacecraft and also from the NOAA Geostationary Operational Environmental Satellite (GOES). Data from each satellite are used for different purposes, but they all yield information indispensable for assessing the state of clouds and weather within the atmosphere.

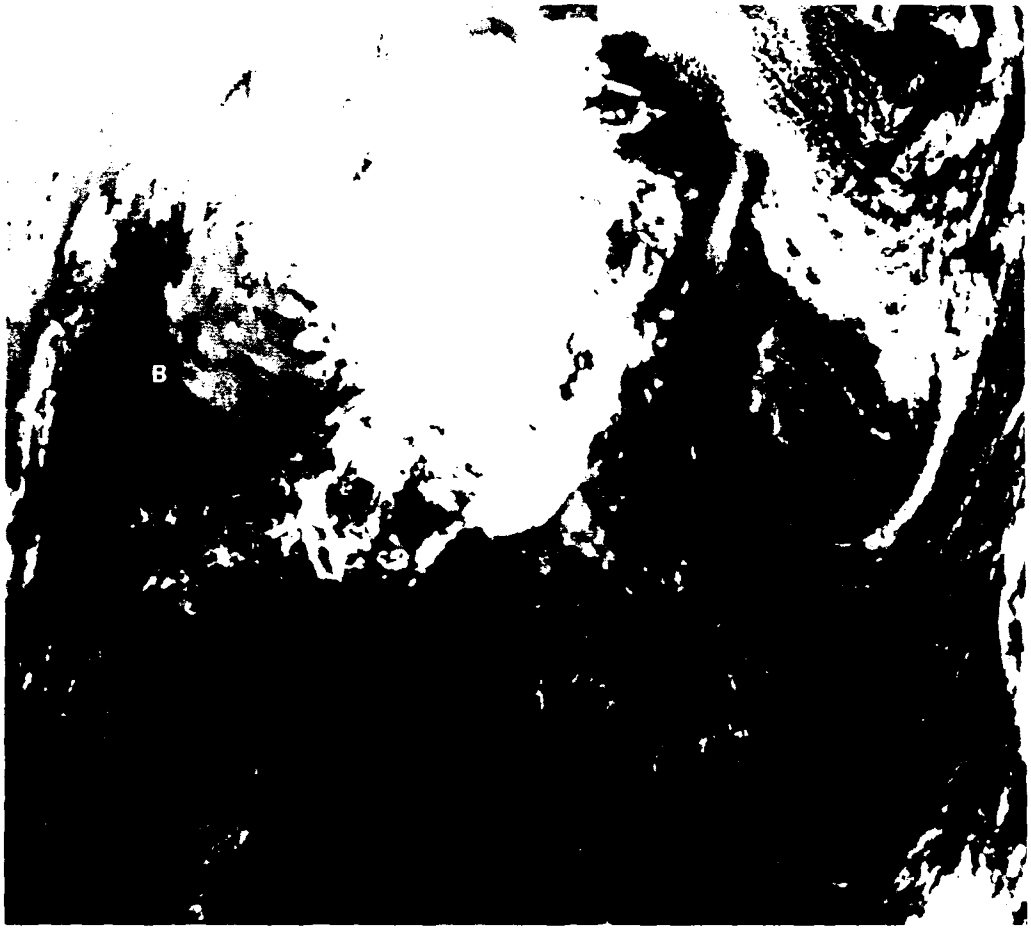
An important tool used by the Satellite Meteorology Branch in the past has been the Man-computer Interactive Data Access System (McIDAS) and, more recently, the AFGL Interactive Meteorological System (AIMS). Currently under development, AIMS is a networked system of minicomputers and image-processing workstations designed to acquire, process, manage, and display satellite imagery along with conventional meteorological surface and upper-air weather data in real time. The interactive capabilities of AIMS allow AFGL scientists to display research results on a color monitor and readily compare those results with the supporting data used to generate them. Limitations to research algorithms are identified and corrected using such interactive capabilities.

Cloud Analysis Using Nighttime Multispectral Imagery: The most significant problem facing cloud analysis based on satellite data is finding low clouds and fogs by using thermal channels. Therefore, a multispectral nighttime low-level cloud analysis method was developed. The analysis technique was tested using multispectral infrared imagery from Channels 3 (3.7 μm), 4 (10. 7 μm), and 5 (11.8 μm) of the OAA-7 Advanced Very High Resolution Radiometer (AVHRR) to generate cloud amounts and cloud top heights for sub-pixel resolution clouds, i.e., for clouds which only partially fill a satellite sensor's field of view. Motivation for this work has come from the success of the AVHRR in identifying low clouds over the oceans at night as part of an automated sea surface temperature (SST) retrieval process. A model for upwelling radiance for each of the three spectral regions 3.7 μm, 10.7 μm and 11.8 μm was written. With this model it is possible to compute upwelling thermal radiances at the top of the atmosphere, given background temperature and emissivity, along with an atmospheric temperature profile. From the radiances, an algorithm for the cloud amount and cloud-top was developed.

Results of the multispectral window-channel algorithm for cloud analysis demonstrated its soundness and success in detecting low clouds and in estimating their tops and fractional cloud cover in nighttime AVHRR multispectral imagery. Test case comparisons using manually selected clear and cloud-filled regions of AVHRR imagery showed good agreement between the multispectral analysis results and human imagery interpretations.

Multispectral Image-Processing Techniques Using GOES Data: One way to differentiate between low and middle-level clouds over large geographic areas in a way that allows for easy identification is the use of false color multispectral imagery. Multispectral images of the earth and its atmosphere are constructed at AFGL by combining images from three channels of the GOES Visible Infrared Spin Scanning Radiometer (VISSR) Atmospheric Sounder (VAS) and NOAA AVHRR sensor packages. The infrared imaging sensors for both of these instruments measure upwelling infrared radiances centered at 3.7 μm, 10.7 μm, and 11.8 μm. In these spectral bands, the atmosphere is nearly transparent and cloud and terrestrial-surface emissions dominate the upwelling radiance measurements. A false color image is constructed by allowing each channel's individual imagery to drive one of the three primary colors (red, green, and blue) of a color monitor. Red is driven by the 3.7 μm imagery, green by the 10.7 μm imagery, and blue by the 11.8 μm imagery. To produce an image with dark backgrounds and bright clouds, the lowest brightness temperatures are assigned the brightest intensities, while the highest brightness temperatures are assigned the darkest intensities, where the measured brightness temperature for a particular channel at a given earth location governs the intensity of its primary color. When the three colors are combined into a single image, the result is a false color image.

The false color image accentuates several striking features (see the figure). First, there is an excellent land/sea demarcation mainly due to the strong con-



NOAA-7 AVHRR 3.7 μm Imagery for June 11, 1982, at 0800 GMT over South Carolina. (Note how well the fog (feature A) contrasts with the adjacent cloudfree land (feature B); 3.7 μm imagery is useful for the detection of nighttime fog and low clouds. Contrasts are poor between low clouds and cloudfree land or oceans in longer-wavelength 10-12 μm imagery, making it difficult to use for detection of low clouds and fogs at night. Next generation DMSP meteorological sensors will be providing imagery at 3.7 μm.)

trast between land and ocean skin temperatures. Second, low clouds appear red-orange because water droplet clouds appear cooler in 3.7 μm imagery than in either 10.7 μm or 11.8 μm. Third, high thin cirrus clouds appear turquoise because proportionally more 3.7 μm radiance emitted from surfaces underneath the cirrus reaches the satellite sensor than does either 10.7 μm or 11.8 μm radiances.

Microwave Studies: Microwave techniques for the passive and active sensing of meteorological parameters from space are being developed at AFGL. Microwave instrument systems are presently, or soon will be, flown on space platforms. The availability of the microwave data will provide the key input for investigations of the retrieval of atmospheric temperature and water vapor profiles, microwave imaging, and multispectral visible/infrared/ microwave image-processing techniques.

Radiative transfer of microwave radiation (3-300 GHz) through clear, cloudy, and rainy atmospheres is being studied. The theory and interpretation of this upwelling microwave radiation are in turn related to the design of microwave sensors for atmospheric temperature and water vapor profiles, and for the detection of rain and other geophysical parameters. These parameters are of importance to Air Force operational weather forecasting and numerical weather prediction (NWP) techniques.

A new sensor, the Special Sensor Microwave/Imager (SSM/I), is an "all weather" meteorological and oceanographic sensor. AFGL was the initiator and technical leader in the development of the SSM/I. The SSM/I will be flown on an operational spacecraft of the DMSP, scheduled to be launched in 1987. It is a passive scanning radiometer which measures energy emitted from the earth-atmosphere system in seven microwave channels with an earth swath that is 1394 km wide. The seven channels consist of four frequencies from 19.35 GHz to 85.5 GHz, with three of the four frequencies employing both vertically and horizontally polarized channels. Relationships among the brightness temperatures from the various channels provide a means to determine several geophysical parameters.

A simulated set of SSM/I microwave brightness temperatures, provided by Hughes Aircraft company, is being used at AFGL to develop techniques to process and display SSM/I data. From a set of microwave brightness temperatures, values of specific environmental parameters can be derived. Image-processing techniques have also been developed to display such retrieved parameters on AIMS in a clear and succinct form.

Automated Cloud Analysis: The Air Force Global Weather Central (AFGWC) at Offutt Air Force Base, Nebraska, has been performing operational cloud analyses on a global scale since January, 1970. The current cloud analysis model, known as the Real-Time Nephanalysis (RTNEPH), has been in use since August 1, 1983, and is an updated version of the original 3-Dimensional Nephanalysis model (3DNEPH) described by Fye (1978). RTNEPH routinely provides a global analysis of total cloud cover and cloud layer amount for a variety of operational and research users. Cloud analysis is performed by analyzing satellite imagery from the DMSP Operational Linescan System (OLS) sensor and merging the results with surface observation reports. AFGL has been tasked with improving the satellite data processing portion of the RTNEPH and with investigating the addition of new channels to the analysis.

Several problem areas have been identified with the RTNEPH satellite processor as it currently exists. The visible cloud-detection algorithm must contend with DMSP satellites that fly close to the terminator. Visible data collected near the terminator contain nearly saturated regions where the sensor looks back toward the sun. For this reason, the visible processor of the RTNEPH generally ignores early morning visible data. However, improved models of bi-directional reflectance may allow some of these data to be used by the RTNEPH. The infrared cloud detection algorithm tends to fail in situations when thermal contrast between the cloud and the background is weak, such as low stratus over cold ocean. AFGL scientists have shown that the addition of one or more thermal channels can significantly improve the detection of low clouds. Another problem area in the RTNEPH is estimating the coverage of small-scale clouds. Improvements in processing visible data may be realized by a new algorithm which has been developed, while improvements in processing infrared data are possible using multichannel models.

Theory of Differential Inversion: Satellite-based techniques for remote temperature sounding of the atmosphere may be grouped into three classes: statistical, quasi-physical, and the truly physical using inverse transfer theory. In the statistical methods, the most probable temperature profile is sought which fits the observed radiance values. The physics is completely ignored. In the quasi-physical approach, of which the Chahine method may serve as an example, an initial profile is assumed which then "relaxes" to the observed radiances. Only the last method recognizes the fact that the temperature profile is physically specified as an inverse transform of the radiance profile. With the differential inversion technique, the temperature inference problem has received its solution by equating the temperature at an atmospheric level to a linear sum of the radiances and their local derivatives weighted by coefficients related to the weighting function.

Because of its importance, the reasoning which led to the differential inversion technique (but not the mathematics) is included here. Transfer theory relates the externally viewed thermal emission to the integral transform of the Planck intensity over pressure, and a kernel weight function which depends on the line character of the sampled frequency interval. Except for the Laplace kernel, the inverse operation has proved intractable because of the nonexponential character of the weight function. With a differential deconvolution approach, the inverse transform difficulty has been bypassed using a theorem relating the Planck intensity to the local behavior of the radiances at the conjugate pressure level. This differential inversion technique has been generalized to treat weight functions of arbitrary character.

Although the differential inversion method provides the mathematical and physical solution of the temperature inference problem, much yet remains to be done before the algorithm can be operationally used on the DMSP system. The main problem is the determination of the limits of inversion error posed by the accuracy to which the radiances are known. In other words, does a useful temperature inference make impossible demands on the radiance data? This problem is being addressed under the "Differential Spectroscopy for Remote Temperature Sounding" contract with Creative Optics, Inc. Although a positive result is avidly sought, even a negative finding would be helpful in exposing what temperature information can or cannot be meaningfully inferred.

Once these inference limits are firmly established, we may then proceed with the construction of an objective temperature-sounding algorithm with only engineering, and not analysis, difficulties to overcome.

BATTLEFIELD WEATHER

The Battlefield Weather Observation and Forecast System (BWOFS) is an advanced development program that, when fielded, will eliminate critical shortfalls in tactical weather support to Air Force and Army operations. The objective of BWOFS is to develop methods to gather vital weather information and process it for use by battle staff planners and aircrews. It provides a key to optimizing force effectiveness during varying weather conditions. To meet this objective, AFGL divided the BWOFS into two components. The first component does the target area data acquisition. The second component, called Tactical Decision Aids, applies the data using a series of algorithms which combine environmental data with target intelligence and weapon system characteristics to provide an electro-optical effects forecast.

Weather Data Within Battle Areas: As defined by the Military Airlift Command's Statement of Need (MAC SON 508-78 for Pre-Strike Surveillance/Reconnaissance System, or PRESSURS), the Air Force critically needs the ability to observe and collect weather data at points within uncontrolled or enemy-controlled battle areas and airspace. Data must be processed and transmitted for use in Tactical Air Force decision assistance at in-theatre weather facilities. Weather is a major factor in determining the success or failure of tactical air missions. Timely weather data, plus a knowledge of its effect on Air Force systems, is vital to the battle director in making tactical decisions. To accomplish this, these data must be provided to the in-theatre weather facilities in near real-time.

MAC SON 508-78 requires measurements of cloud areal coverage (and the altitude of tops and bases), wind, temperature, pressure, humidity, path transmission, and contrast transmission. AFGL has developed a concept which involves the use of an enhanced satellite system complemented by unmanned air vehicles (UAVs). Weather satellite enhancements include improved ground-data processing, distribution, and display using tactical vans now supporting TAC/TAF field operations. The UAV will provide weather observations that cannot be obtained from a satellite, while the satellite would continue to provide critical information which could be used to determine when UAVs are needed. A critical sensor, a nephelometer, developed to measure the cloud parameters and visibility, was flight-tested. Results showed that the nephelometer can resolve cloud boundaries and measure the visibility to within stated PRESSURS requirements.

Full verification of the UAV concept awaits testing during the Concept Validation Phase of the program, scheduled to begin in 1987.

Tactical Decision Aid Development: Air Weather Service Geophysical Requirement 9-73 (Forecasting Aids for Precision Guided Munitions) states a need for forecaster aids which will allow an estimate of maximum target detection and lock-on range based on known sensor target and environmental parameters. These aids, called Tactical Decision Aids (TDA), are being developed for use by battle staff planners and air crews to insure effective employment of precision guided munitions (using infrared, television, laser, and millimeter wave guidance systems) under battlefield conditions. Tactical Decision Aids were developed which can be used to predict the performance of 1.06 μm laser designator, television, low-light-level television, and 8-12 μm infrared precision-guided munitions and target-acquisition systems under a wide variety of environmental conditions.

Calculator versions of these TDAs were used by weather forecasters and decision makers in the field. The TDA has been successfully employed at a number of locations. It continues to be used for test and operational support on infrared systems. A microcomputer version of the TDA was developed and turned over to the Air Weather Service. This version was developed specifically for the Zenith 100 and Zenith 150 microcomputers which are used at base weather stations around the world. The TDA has been evaluated by Air Weather Service units worldwide and the reaction is that the product is "terrific."

SYSTEMS DESIGN CLIMATOLOGY

Air Force systems and materiel must be designed to operate in, and withstand, atmospheric extremes that have a vital effect on the successful accomplishment of the Air Force mission. Overdesign may be uneconomical or even ineffective, whereas underdesign can result in failure, with possible loss of life and equipment. As a result, materiel and systems design require careful consideration of various atmospheric elements, including their variability and extremes. Limitations of current meteorological data make it necessary to develop theoretical and empirical models, or algorithms, and to improve the utility of available climatic information as well as to provide more accurate estimates of the structure and variability of the atmosphere. Consequently, climatological research is continuing in order to better describe the atmosphere and its effect on Air Force plans and the design and operation of equipment.

Environmental Simulation and Statistical Modeling: The goal has continued in the past two years to stochastically portray weather conditions in prescribed spatial and temporal domains, and to estimate the climatic probabilities of such conditions or events. This would be done in all or a fraction of the space, all or part of the time, or for an interval of time within a larger period of time. The effort has concentrated on cloud-cover and the associated problems of cloud-free line of sight (CFLOS) and cloud-free intervals (CFI). The basic model, for the stochastic production of a field of clouds, is the Boehm Sawtooth Wave (BSW) model, but it's been advanced to three and four dimensions, thus providing simulations and probabilities in horizontal and vertical pictures and in changes of time. Since the temporal changes were found to approximate the Ornstein-Uhlenback (O-U) process, the BSW model was adapted to yield simulations that closely resemble the O-U process, especially with regard to temporal correlations. The model's parameter, scale distance, is conceptually the distance (km) between two locations (1,2) over which the correlation coefficient between the conditions (x_1, x_2) is 0.99. Values of scale distance were investigated for many places, times of year, and times of day. Likewise, the parameter relaxation time (hours) of the O-U process is conceptually the time interval over which the correlation coefficient is 1/e (0.368). It was found to vary from a few hours to 35 hours for cloud cover.

During 1985-86, simulation modeling was focused on applications for the Strategic Defense Initiative (SDI). The SDI office is concerned with the effects of clouds on the ability of ground-based laser systems to operate with high reliability over the systems' expected lifetimes. To assess cloud effects, SDIO needs estimates of the frequency and duration of system downtime for varying numbers of sites. Using the Boehm Sawtooth Wave model, AFGL developed and programmed a method to simulate the nature of system downtime due to clouds. This method produces cloud-free line of sight and cloud-free arc statistics at each receiver site, given the site's cloud climatology and various correlation coefficients. These statistics are then analyzed for systems of multiple sites, yielding downtime statistics for combinations of sites for various time-intervals, from 5 minutes to 24 hours. Concurrently, there are several approaches underway to verify the accuracy of the above model as used to estimate system downtime. We've made a "rough-and-ready" comparison using sunshine data, in which we've assumed a sunny line of sight is essentially equivalent to a cloud-free line of sight. A more detailed comparison was begun in which a contractor is comparing the output from the model with cloud-cover statistics derived from GOES satellite pictures. The results are encouraging and suggest this model is worth further study. Accordingly, AFGL is planning the establishment of a network of whole-sky imagers whose output will be digitized and used for a more realistic comparison than is possible with any existing data set. This work represents the broadening of the Boehm Sawtooth Wave model into the four dimensions of space and time. With the latest developments, we expect the model will be of increasing interest for modeling other meteorological phenomena.

A World Atlas of Total Cloud Cover was published in this period, to present paired values of the two parameters of mean sky cover and scale distance. This publication describes the use of these parameters to compute the probability of clear, partial cover, and overcast conditions, allowing the floor-space to vary.

At Tel Aviv University, LANDSAT images were carefully studied with respect to the threshold of brightness and the delineation of cloud structure. Individual clouds have been defined objectively as entities with or without holes within the clouds. Methods of measuring perimeter and area, and the relation between the two as a fractal dimension, are described in the final report. Rules have been developed to estimate minimum intercloud distances and their frequency distributions. Cloud-size distributions were best fitted to a power law. Minimum distances between clouds were fitted to a log-normal distribution. Results were presented for 17 locations spread over the world's oceans. The results on the fractal nature of clouds were found to be partly in agreement, partly at variance, with those of earlier pioneering investigations. The differences were related to two categories of cloud sizes: those with radii less than, and greater than, 0.5 km.

Climatic Data for Systems Design: The primary military standard used to determine climatic design and test requirements for systems and equipment developed by all DoD agencies is the responsibility of AFGL. A revised version of the standard, "MIL-STD-210C, Climatic Information to Determine Design and Test Requirements for Military Systems and Equipment," was completed at the end of CY86. AFGL was the lead organization for this tri-service effort.

The revised standard was expanded to include regional climatic information in addition to the worldwide data that was provided in the previous version. Temperature and density profiles from the surface to 80 km based on extremes at specified altitudes were developed at AFGL and added to the standard to optimize the design of aerospace systems traversing the atmosphere. The climatic elements presented in the standard were also updated to include the latest information, and background data were added to facilitate trade-off analyses.

Most importantly, the guidance provided for using the standard was changed to reflect current DoD policy on tailoring the design and testing of materiel. This will enable the user to establish appropriate design considerations based on the operational requirement of each system or item under development.

Rainfall Rate Modeling: The Air Force requires frequency distributions of 1-minute precipitation rates at locations throughout the world to determine design and operational requirements for many types of equipment. Precipitation, especially at heavier intensities, attenuates microwave signals used by Air Force systems in satellite detection and tracking, communications, air traffic control, reconnaissance, and weaponry. Erosion due to rain affects helicopter rotor blades, leading edges of aircraft and missiles, and fuses on airborne ordnance. Intense rainfall can cause jet engines to malfunction and can penetrate protective coverings on exposed electronic and mechanical materiel.

A recently completed research effort provides new models of extreme rain rates from the surface to 20 km. The model profiles specify 1-minute rain rates, associated drop-size distributions, precipitation water content, and cloud water content at 2 km intervals. These profiles are an important consideration in the design of aerospace systems.

More recently, an effort was begun to derive statistics on the frequency and duration of 1-minute rainfall rates for locations throughout the world. These have become very important considerations in the design of satellite communication systems using ehf frequencies because rain is the major cause of attenuation of these signals. The 1-minute rates need to be extracted from original rain chart recordings using specialized techniques and then modeled to get estimates of rates where data are not available. The rain rates can be used to estimate system outages due to rain and the need for space diversity of terminals or other alternatives.

BOUNDARY LAYER METEOROLOGY

The planetary boundary layer extends from the earth's surface to a height of about 1.5 km. By definition, it is that layer of the atmosphere from the earth's surface to the geostrophic wind level, or to that level at which the frictional influences of the earth's surface become negligible.

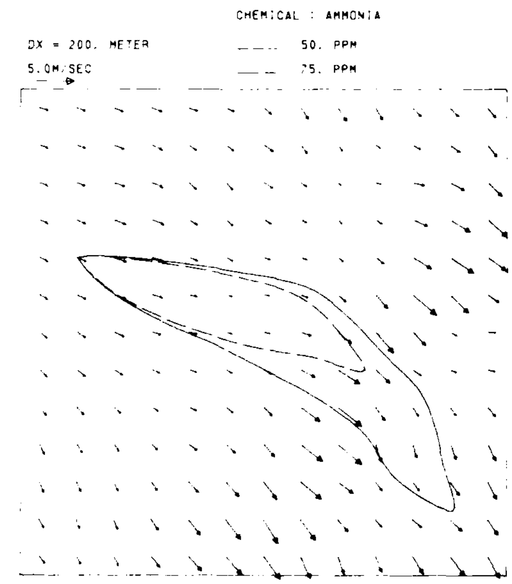
Understanding the structure and dynamics of this layer is important to the Air Force since so many Air Force systems operate within it. Improved techniques for the detection and prediction of meteorological elements in this layer are required to support Air Force systems and operations such as advanced military communication and surveillance systems, and operations that may be impacted by inadvertent or planned toxic chemical releases.

Anomalous Microwave Propagation: Surveillance radars, digital microwave radios on long line-of-sight (LOS) communication links, and tactical digital troposcatter radios all experience significant anomalous propagation events that limit these systems from achieving desired performance objectives. An atmospheric refractivity "event" that can adversely affect one of the above systems may result in enhanced performance on another and be neutral in its effect on a third. Specific system geometry or its method of deployment is very important in determining the magnitude of the effects of these refractivity events.

A prior field program had obtained measurements of the mean refractive profile, n(z), on line-of-sight communication links in New England and in southern Germany. These data were used in conjunction with a ray trace model to document the atmosphere's role in affecting multipath delays and variations in the angle of arrival of the incident energy. These results indicate maximum delays to be a function of path distance to the half power for long paths. This is more optimistic than the distance to the second power previously proposed.

The measurement phase of the troposcatter radio tests was completed. These tests involved obtaining profiles of the fine-scale refractive fluctuations represented by the refractive index structure function, $C_n^2(Z)$, in addition to the mean refractive profile, n(Z). The structure function profiles were obtained by a microwave refractometer mounted on a light aircraft. While this refractive turbulence is a source of noise to most communication systems, it is necessary to troposcatter radios because it is the scattering medium. These data have been used in a two-dimensional and three-dimensional troposcatter propagation model to demonstrate the sensitivity of the delay spread to atmospheric effects and path geometry. The influence of the vertical structure of C_n^2 on the radio delay spread was demonstrated, and the possibility of orographic effects causing multiple scattering effects has been hypothesized.

Toxic Chemical Dispersion: Accidental chemical spills can occur anytime when storing or transporting chemicals, whether it be a civilian or military operation. For emergency response planning and operations, models are needed for predicting the hazard area resulting from a spill.



Predicted Terrain-induced Wind Field and Concentration Isopleths from a Continuous Ammonia Spill. (Wind at spill site is 2 m per second at 290° but varies throughout the 2.4 × 2.4 km domain due to the hilly terrain, which varies as much as 200 m in elevation.)

Several models are being developed to handle gas spills of neutral density and heavier-than-air gases over both smooth and complex terrain. These models include AFTOX, a Gaussian puff dispersion model; a high-resolution surface-layer windflow model; WADOCT, a complex terrain dispersion model; and a heavy gas dispersion model. The AFTOX model computes hazard distances resulting from continuous or instantaneous, liquid or gas, elevated or surface releases from a point source. This model is currently being evaluated by the Air Weather Service as a possible replacement for the Ocean Breeze Dry Gulch Dispersion Model. The surface-layer windflow model was acquired from the U.S. Army Atmospheric Sciences Laboratory at White Sands, New Mexico. The model performs a variational analysis of surface-layer winds in the x-y plane to induce an initial wind field to conform to constraints of topography, buoyancy forces, momentum advection, and mass conservation. Several improvements have been made in the model and validation studies have been done using the meteorological and terrain data from Vandenberg AFB, California. The model was reprogrammed to run on the Zenith Z-100 microcomputer. The AFTOX Model and wind flow model have been combined into a complex-terrain dispersion model called WADOCT. In this model, the concentration contours are distorted by the wind field defined by the wind flow model as shown in the figure. A plot of the wind field and concentration contours is provided. A heavy gas dispersion model is being developed under contract. This model takes into account the various physical, chemical reaction, and thermodynamic phenomena that take place when the chemical is suddenly released to the atmosphere. The model is designed specifically for nitrogen tetroxide, chlorine, hydrogen sulfide, ammonia, sulfur dioxide, and phosgene.

Boundary Layer Modeling: To better understand the dynamic and physical processes that take place in the planetary boundary layer, modeling work was done to establish practical methods for the prediction of three-dimensional turbulent atmospheric flow over complex terrain when environmental conditions at the boundaries of the flow volume are prescribed. A second-order turbulence model was developed. The model is constructed from first principles, and incorporates state-of-the-art concepts in turbulence modeling. It has been exercised in unsteady one-dimensional computations simulating the growth of the surface mixed layer of the atmosphere, and that of two-dimensional steady boundary layer growth. An efficient numerical algorithm for the implementation of a three-dimensional computation over terrain has been partially developed, but not brought to completion.

GROUND-BASED REMOTE SENSING

The environment is a key factor in the operation of nearly all Air Force weapon, surveillance, and communication systems. To meet the need for more accurate, precise, and timely weather support for Air Force operations, the Atmospheric Sciences Division develops techniques for the remote sensing of adverse environmental conditions and the incorporation of the derived information into precise weather advisories and forecasts for times up to several hours. Progress during 1985 and 1986 included development of: (1) automated techniques for detection and warning of atmospheric hazards based on Doppler weather radar observations, (2) techniques for identifying the microphysical characteristics of cloud and precipitation particles from techniques for short-term forecasting of clouds and precipitation using combined data from weather radars and satellites. During 1986 the Ground Based Remote Sensing Branch collaborated with other branches of the Atmospheric Sciences Division in a program designed to quantify the attenuation of microwave signals at multiple frequencies and to relate the attenuation to meteorological conditions.

Automated Doppler Weather Radar Analyses: The Next Generation Weather Radar (NEXRAD) network is soon to be deployed around the country. This new radar system will provide greatly improved weather detection and prediction capabilities, particularly for severe weather events such as tornadoes, hailstorms, and flash floods. Doppler weather radar research at AFGL provided much of the scientific foundation for the NEXRAD Program, and AFGL has been heavily involved with the NEXRAD Program from its beginning. Development and testing of algorithms for the NEXRAD system are ongoing activities at AFGL. The primary focus has been on the detection and short-term warning of severe weather hazards at the ground and in the lowest few kilometers above the ground, with the ultimate aim of significant reduction in casualties and property loss by destructive weather phenomena. The severe weather hazards addressed in these studies during 1985 and 1986 include tornadoes, wind shear, icing, turbulence, and the high winds associated with hurricanes and intense extratropical cyclones.

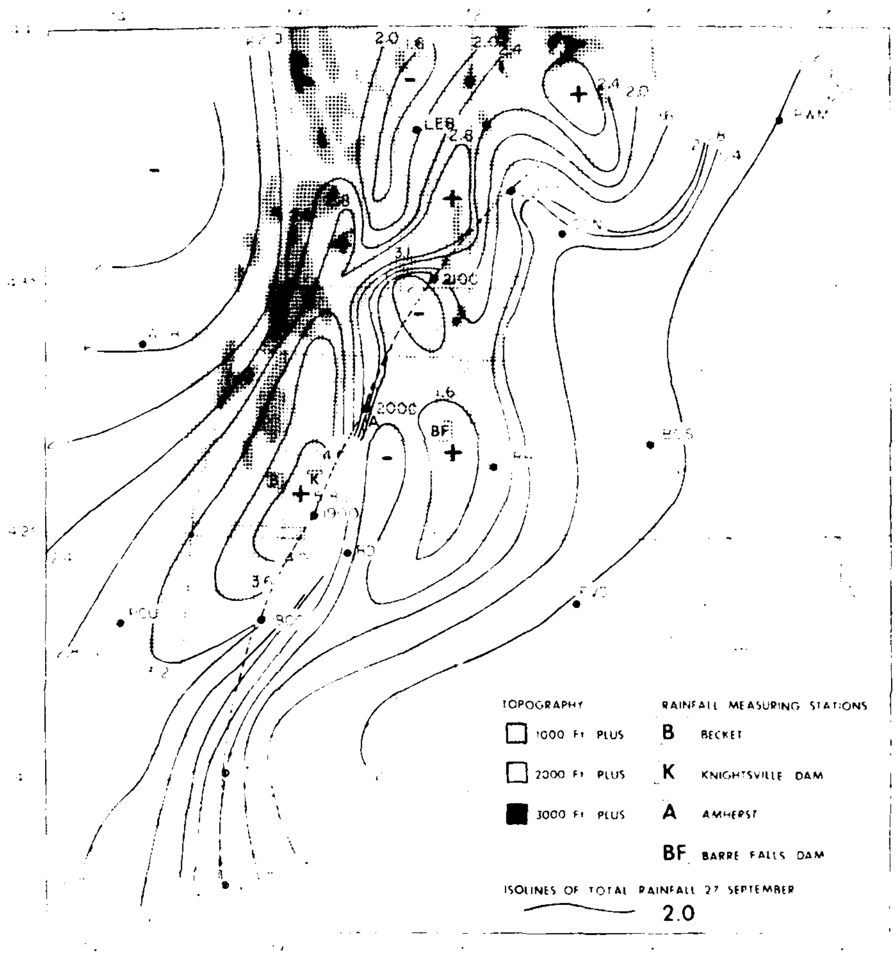
Mesocyclones, which are rotating regions located within some intense and well-organized thunderstorms, are the parent circulations of the great majority of tornadoes and all of the violent ones. Because about half of all radar-detectable mesocyclones have produced one or more tornadoes, and over 90 percent have produced some form of severe weather at the ground, their identification is crucial for improved warnings of severe storms as well as tornadoes. Studies have included a search for a mesocyclone precursor through rotational and convergent interstorm motions, and a search for a predictor of tornado occurrence and intensity in the rotational kinetic energy development of the parent mesocyclone. Also an algorithm has been developed for automated identification of mesocyclones from a single Doppler radar. This algorithm has the capability to detect tornado vortex signatures when the radar beamwidth is less than the diameter of the tornado.

An algorithm for the automated detection of mesocyclones has been developed which identifies large mesocyclones as well as tornado-scale motions. Mesocyclones are usually of the order of several kilometers across, while the tornado circulations are typically 1 km or less. In addition, for any detected circulation, the algorithm identifies the horizontal and vertical extent, temporal persistence, average shear, momentum, direction of rotation, and rotational kinetic energy. All these parameters have been carefully examined to determine their value for the warning of tornadoes. The rotational kinetic energy, or a modification thereof, may be the most useful parameter. The excess rotational kinetic energy (ERKE), defined as the amount of measured rotational energy in excess of that required for the circulation to be considered a mesocyclone, is computed for each observation of a storm. From the ERKE a tornado predictor has been developed which predicts not only occurrence but also intensity. This predictor requires that (1) the ERKE must be at least as large as the climatological mean value for mature mesocyclones, (2) this threshold must be exceeded below 5 km altitude, and (3) the excess must persist for at least 5 min. For a tornado to be classified as violent the ERKE must exceed a threshold value twice that of the climatological mean. With these criteria the predictor was successful for nine out of ten storms examined; the lead time to the first, usually weak, tornado produced by a particular storm was of the order of a few minutes, and the lead time to the most intense, but non-violent, tornado was of the order of tens of minutes. However, when a prediction of a violent tornado was made, the predictor was 100 percent accurate, with lead times of tens of minutes. This excellent predictability for violent tornadoes is indeed fortunate, because tornadoes of this class, although rare, kill and injure many more people than the more common strong or weak tornadoes.

Aircraft are particularly susceptible to accidents in takeoff and approach corridors because of their proximity to the ground. Several crashes have, in fact, occurred when aircraft experienced significant variations in lift upon encountering substantial environmental wind shear. These wind changes tend to be associated with convective storm outflow, sea breeze fronts, and synoptic fronts. Detection of the location of these features in real time could provide valuable guidance to air traffic controllers and pilots alike. Considerable research has been directed toward determining the detectability by Doppler radar of these low-level shear phenomena and developing and testing automated detection techniques where appropriate. The primary effort has been on the detection of the outflow from convective storms since this appears to be the primary cause of air crashes associated with wind shear. These outflows are the product of downdrafts that occur within all convective storms. A great many storms produce strong downdrafts called downbursts. Downbursts are defined as any strong downdraft that produces damaging winds at or near the ground. There are two categories of downbursts, namely, microbursts (horizontal extent less than 4 km across) and macrobursts (greater than 4 km). The most hazardous tends to be the microburst. Microbursts tend to kick up enough debris, have enough precipitation, or have sufficient refractive index gradients for detection by microwave Doppler radar. A very distinctive divergence signature is produced by microbursts in the radial velocity fields at the very lowest elevation angles. An algorithm was developed to detect this divergence signature and was found to be quite successful on the limited data available.

A common characteristic of gust fronts is the presence of gradients of the radial velocity. Techniques for the estimation of these gradients in real time were examined. The approach that was adopted was to compute Doppler velocity gradients in both azimuth and range and place them on a rectangular grid for combination into a single two-dimensional gradient of the radial velocity. The magnitude of this combined gradient relative to a specified threshold value yields a product which enables the identification of gust fronts. The gradient computation scheme used in this analysis has become the Combined Shear Algorithm in the NEXRAD library of Category 1 algorithms, those being implemented in the prototype radar systems.

Hurricane Belle, in 1976, was the first tropical storm to be observed by Doppler radar. These observations by AFGL indicated distinct asymmetries in the radial velocity fields, which at that time were attributed to the curvature of the wind field. Since that time, there has been some rethinking of this problem and a study was conducted to determine what other effects might contribute to these anomalies. Curvature and crosswind shear were found to result in the asymmetries observed in the Hurricane Belle



Isohets of Total Accumulated Rainfall from Hurricane Gloria, September 27, 1985. (Contours are at intervals of 0.2 inch of rain. Storm center is presented as a series of circles joined by straight line segments. Times are GMT.)

data. Techniques were developed to recover the downwind shear, difluence, and the sum of curvature and crosswind shear from the Doppler velocity data. These later techniques were then applied to data collected on Hurricane Gloria as it crossed Long Island and moved into western New England on September 27, 1985. This analysis revealed pronounced decay of both circulation and maximum wind speed around the eye region after landfall nearly three hours before confirmation by more direct radar measurements (see the figure). Negative downwind shears, due to frictional loss over rough ground, and persistently positive difluence were also measured. This type of diagnosis, utilizing wind field derivatives recovered from the pattern of scanned Doppler velocities, offers great promise for remote and early assessment of the trend in intensity of hurricanes and severe extra-tropical cyclones and is forming the basis of a hurricane intensity algorithm being developed for NEXRAD.

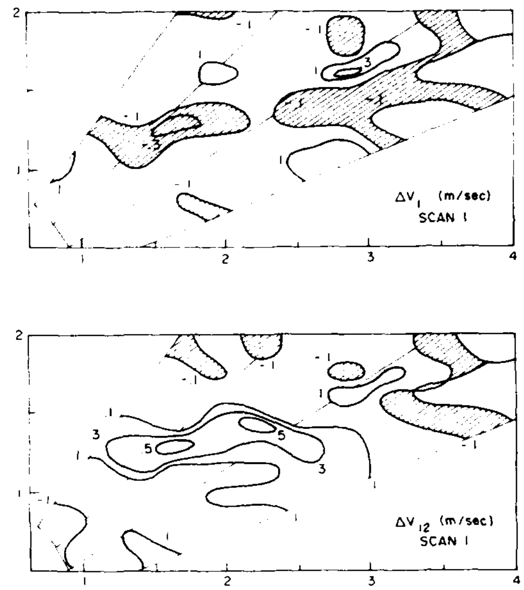
Aircraft icing is most often caused by small (less than 60 micrometers in diameter), supercooled liquid water droplets, too small to be detected by radar. Therefore, there is reason to expect icing encounters when supercooled raindrops are present. Normally when ice particles fall from their region of generation through the zero degree level they melt and produce a "bright band" in the radar reflectivity measurements. Since supercooled water and ice particles are not likely to coexist, from the presence of a bright band one can deduce that there is no supercooled liquid water. Conversely, the absence of a bright band within a precipitation region that extends above and below the zero degree level might well indicate the presence of supercooled liquid water and the absence of ice particles. This reasoning is the basis of the algorithm developed here. The automated algorithm has been implemented and awaits testing with coincident radar and aircraft data.

Short-Term Cloud and Precipitation Forecasts: Methods are being developed to supply precise and accurate short-term forecasts of clouds and precipitation. The ultimate objective of this work is to provide Air Force commanders with the margin of time necessary to implement strategies to mitigate the effects of clouds and precipitation on future satellite-to-ground communications systems. The Remote Atmospheric Probing Information Display (RAPID) system, on which the software is developed and tested, incorporates a Digital Equipment Corp. VAX 11/750 minicomputer and an ADAGE 3000 image processor. This system receives satellite imagery from the AFGL Interactive Meteorological System (AIMS) at Hanscom AFB and data from the AFGL Doppler weather radar through another minicomputer via a local area network (LAN). Before any data analysis occurs, the two data sets are transformed to a common coordinate system. The data are then loaded into the ADAGE image processor for additional analysis. The goal of these efforts is to generate 0 - ½ hour forecasts of clouds and precipitation.

The prediction of future precipitation distributions is a two-step process, namely, feature extraction and extrapolation. The feature extraction process identifies the precipitation intensity contours of interest and then maps them into quantities suitable as input to extrapolation algorithms. The mapping techniques decompose each boundary contour into a series of segments, which in turn are described as lists of contiguous unit vector directions. List attributes such as total vector number, orientations, and displacements from a suitable reference position are the quantities which are monitored by extrapolation algorithms and provide the basis for the forecasting process. Thus forecasting the evolution of a precipitation intensity contour ultimately becomes a process of forecasting the evolution of the direction vector lists. Because the behavior of these quantities is not known beforehand and may not be readily identified with meteorological observables, the extrapolation algorithms are of a purely statistical nature. Emphasis is on simple exponential smoothing and adaptive, or error-correcting, techniques. Currently the development and verification of algorithms are being performed with radar and satellite data acquired during the passage of Hurricane Gloria over New England in September, 1985.

Precipitation Characteristics: The microphysical properties of clouds and precipitation are of significant practical concern to the Air Force because of their effects on: (1) the depolarization and attenuation of terrestrial and satellite communication systems, (2) the safe performance and even the survivability of airframes in regions of hail or heavy icing, and (3) the erosion of reentry vehicles.

The need for remote-sensing techniques for characterizing the microphysical parameters of cloud and precipitation systems has led to the investigation and development of polarization diversity radar techniques for deriving information on the size, shape, number concentration, and thermodynamic phase of cloud and precipitation particles. The polarization techniques rely on the fact that many



Differential Doppler Velocity Techniques. Velocity differences related to the polarization of a radar signal, measured in a vertical section through a cloud, reveal that near the melting level (about 1.7 km altitude) the least spherical particles (associated with the quantity Δv_1) are falling fastest but that the particles with the greatest tendency to a common orientation (associated with Δv_{12}) are falling slowest. The former are probably large, irregularly shaped ice particles known as graupel. The latter are probably large aggregate snowflakes, which tend to fall slowly, with their largest dimension oriented horizontally. These measurements represent the first use of a new weather radar technique which permits the discrimination of ice particles of different shapes in precipitation.)

types of hydrometeors are non-spherical and tend to orient themselves in a preferred way in response to aerodynamic or electrical forces. The hydrometeors thus constitute an anisotropic scattering and propagation medium. This characteristic of the medium has implications for the performance of surveillance, guidance, and communication systems in cloud or precipitation environments. The anisotropy of the medium makes it possible to use the relative amplitude and relative electromagnetic phase of the received signals of opposite polarization to derive the microphysical information. The polarization parameters, together with the conventional reflectivity and Doppler velocity parameters, permit the most comprehensive possible description of the scattering and propagation media from a single radar.

A new analytical technique, the differential Doppler velocity technique, has been shown to yield a nearly unambiguous determination of the presence of ice-phase hydrometeors in a scattering medium and, under some conditions, to yield an indication of the type of ice particles, e.g., snowflakes or graupel. This technique, the theory of which was developed during 1984 and 1985, was applied to a set of data from the 8.6-mm wavelength polarization diversity radar operated by the NOAA Wave Propagation Laboratory to obtain a highly detailed description of the evolution of hydrometeors near the melting level (see the figures). Work continued on the modification of the AFGL 1-cm wavelength dual-frequency Doppler radar to enable full polarimetric measurement capability. The first use of this radar to measure the polarization differential reflectivity in precipitation occurred late in 1986, and the initial report on the system will be published in 1987. When the modifications are completed, the radar will be capable of measuring simultaneously the received signals of orthogonal polarizations and thus will enable the measurement of all the polarimetric parameters needed for investigating the microphysical structure and evolution of clouds and precipitation.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

BANTA, R.M.
Late-Morning Jump in TKE in the Mixed Layer over a Mountain Basin
J. Atmos. Sci. 42 (15 February 1985)
Daytime Boundary-Layer Evolution over Mountainous Terrain. Part II: Numerical Studies of Upslope Flow Duration
Monthly Weather Rev. 114 (June 1986)
Cumulus Cloud Initiation by a Mountain Boundary-Layer Model
Proc. Internat. Cloud Modeling Wkshp. (15-19 July 1985)
Sensitivity Studies on the Continentality of the 19 July 1981 CCOPE Cumulonimbus
Proc. Internat. Cloud Modeling Wkshp. (15-19 July 1985)

BARNES, A.A., JR., and COHEN, I.D.
Microstructure Variations in the Life of Extra Tropical Cyclones
Proc. 6th Internat. Cloud Phys. Conf. (21-28 August 1984)

BERTHEL, R.O., and PLANK, V.G.
Data Reduction Techniques Used in the Determination of Precipitation Rates from Electronic Weight Measurements
Proc. Wkshp. on the Correction of Precipitation Measurements (1-3 April 1985)

BOHNE, A.R., and CHMELA, A.C.
Storm Structure During Aircraft Lightning Strike Events
J. Geophys. Res. 91 (20 November 1986)

BOUCHER, R.J., and WIELER, J.G.
Radar Determination of Snowfall Rate and Accumulation
J. Climate and Applied Meteor. 24 (January 1985)

BUNTING, J.T.
Clouds and Cloudiness, Nephanalysis in *The Encyclopedia of Climatology,*
ed. J. E. Oliver and R. W. Fairbridge, Van Nostrand Reinhold Co., New York (1986)

BUNTING, J.T., and HARDY, K.R.
Cloud Identification and Characterization from Satellites in *Satellite Sensing of a Cloudy Atmosphere: Observing the Third Planet,*
ed. by A. Henderson-Sellers, Taylor and Francis, London (1984)

CHAMPION, K.S.W.
Recent Advances in Upper Atmospheric Structure
Adv. Space Res. 5 (1985)
Atmospheric Structure for Low Altitude Satellites and Aerobraked Orbital Transfer Vehicles
Preprint Vol. AIAA 24th Aerospace Sci. Mtg. (6-9 January 1986)

D'ENTREMONT, R.P.
Low and Midlevel Cloud Analysis Using Nighttime Multispectral Imagery
J. Climate and Applied Meteor. 25 (December 1986)

DYER, R.M., GLASS, M. (AFGL); and HUNTER, H.E. (Nichols Research, Huntsville, AL)
The Classification of Ambiguous Ice Particle Shadowgraphs by Consensus
J. Atmospheric and Oceanic Tech. 2 (December 1985)

GLASS, M.
Cloud Microphysical Model Experiments; The Influence of Cloud Condensation Nuclei on Precipitation Development
Proc. of Internat. Cloud Modeling Wkshp. (July 1985)

KING, J.I.
Differential Inversion and the Limits of Objective Temperature Inferencing
Proc. Second Conf. on Satellite Meteorology/ Remote Sensing and Applications (13-16 May 1986)
Theory and Application of Differential Inversion to Remote Temperature Sensing in *Advances in Remote Sensing Retrieval Methods*, ed. by A. Deepak, H.E. Fleming, and M.T. Chahine, Deepak Pub. (1985)

KLEESPIES, T.J. (AFGL); and McMILLIN, L.M. (NOAA/NESDIS, Washington, DC)
An Extension of the Split Window Technique for the Retrieval of Precipitable Water
Proc. Second Conf. on Satellite Meteorology/ Remote Sensing and Applications (13-16 May 1986)

LEE, Y. (MIT/Lincoln Lab., Lexington, MA); and BARNES, A.A., JR. (AFGL)
An Analysis of Particulate Removal from the TITAN Rocket Exhaust Cloud
J. Climate and Applied Meteor. 24 (June 1985)

McCLATCHEY, R.A.
Aerospace Meteorology - Past, Present and Future Plans
Proc. AIAA 24th Aerospace Sciences Mtg. (6-9 January 1986)

MARCOS, F.A. (AFGL); and FORBES, J.M. (Boston Univ., Boston, MA)
Thermospheric Winds from the Satellite Electrostatic Triaxial Accelerometer System
J. Geophys. Res. 90 (1 July 1985)

METCALF, J.I.
Interpretation of the Autocovariances and Cross-Covariance from a Polarization Diversity Radar
J. Atmos. Sci. 43 (November 1986)

RAWER, K. (Albert-Ludwigs-Univ., Freiburg, FRG); MINNIS, C.M. (URSI Secretariat, Brussels, Belgium); CHAMPION, K.S.W. (AFGL); and ROEMER, M. (Univ. of Bonn, FRG), editors
Models of the Atmosphere and Ionosphere
Adv. Space Res. 5 (1985)

SCHAAF, C.B., and BANTA, R.M.
Characteristics of Orographically Initiated Convection
World Meteorological Org./TD-No. 108, Scientific Results of the Alpine Experiment (ALPEX) (28 October-2 November 1985)

SEITTER, K.L. (Univ. of Lowell, Lowell, MA); and MUENCH, H.S. (AFGL)
Observation of a Cold Front with Rope Cloud
Monthly Weather Rev. 113 (May 1985)

SNOW, J.W.
Some Cloud Population Statistics
Proc. Symp. and Wkshp. on Global Wind Measurement (29 July-1 August 1985)

SNOW, J.W., GRANTHAM, D.D. (AFGL); TOMLINSON, E.M. (Air Weather Service, Los Angeles, CA); and WILLAND, J.H. (Systems and Applied Sciences Corp., Lexington, MA)
The Characterization of Cumuliform Cloud Fields Using Space Shuttle Photography
Proc. Second Conf. on Satellite Meteorology/Remote Sensing and Applications (13-16 May 1986)

TATTELMAN, P.
Atmospheric Profiles of Temperature, Density, Water Content, and Precipitation Rate for MIL-STD-210C
Proc. 31st An. Tech. Mtg. of the Inst. of Environmental Sciences (29 April-2 May 1985)
MIL-STD-210C, An Improved Menu of Climatic Data to Nourish the Design and Testing Community
Proc. 32nd An. Tech. Mtg. of the Inst. of Environmental Sciences (5-9 May 1986)

TATTELMAN, P., and GRANTHAM, D.D.
A Review of Models for Estimating 1 Min Rainfall Rates for Microwave Attenuation Calculations
IEEE Trans. on Communications COM-33 (April 1985)

ZIMMERMAN, S.P., and KENESHEA, T.J.
Turbulent Heating and Transfer in the Stratosphere and Mesosphere
J. Atmospheric and Terr. Phys. 48 (1986)

PRESENTATIONS AT MEETINGS JANUARY, 1985 - DECEMBER, 1986

BANTA, R.M.
Cloud and Mesoscale Model Experiments
Internat. Cloud Modeling Wkshp., Irsee, Germany (14-20 July 1985)
The Effect of Ridgetop-Level Winds on Upslope Flow in the Daytime Mountain Boundary Layer
7th Symp. on Turbulence and Diffusion, Boulder, CO (12-15 November 1985)
Cloud Model Sensitivity Studies on the Vertical Penetration of Soot
Global Effects Program Tech. Mtg., Moffett Field, CA (25-27 February 1986)

BANTA, R.M., and BARNES, A.A.
Modeling of Atmospheric Moisture Effects on a Nuclear Mass Fire Cloud
IAMAP/IAPSO Joint Assbly., Honolulu, HI (5-16 August 1985)

BANTA, R.M., and HANSON, K.R.
Moist Convection in a Mountain Boundary-Layer Model
7th Conf. on Numerical Weather Prediction, Montreal, Canada (17-21 June 1985)
Numerical Simulations of the Development of Mountain Cumulus Clouds
Internat. Symp. on Short- and Medium-Range Numerical Weather Prediction, Tokyo, Japan (4-8 August 1986)

BANTA, R.M., BERTHEL, R.O., and PLANK, V.G.
A Bulk Microphysics Parameterization Based on a Doubly-Truncated Exponential Distribution and Empirical Relationships
Conf. on Cloud Physics, Snowmass, CO (22-26 September 1986)

BARKER, C.L., and BANTA, R.M.
Preferred Regions of Thunderstorm Initiation over the Colorado Rockies
14th Conf. on Severe Local Storms, Indianapolis, IN (29 October-1 November 1985)

BARKER, C.L., BANTA, R.M. (AFGL); and WURMAN, J. (OPHIR Corp., Lakewood, CO)
Mechanisms for Convective Cloud Initiation over the Colorado Rockies
Second Conf. on Mesoscale Processes, University Park, PA (3-6 June 1985)

BARNES, A.A.
Liquid Water Content and Attenuation in the Melting Layer
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

BENJAMIN, S.G. (PROFS/NOAA/ERL, Boulder, CO); and LANICCI, J.M., Capt (AFGL)
Effects on Dryline Behavior Due to Soil Moisture and Topography: Numerical Results from SESAME I and SESAME IV
14th Conf. on Severe Local Storms, Indianapolis, IN (29 October-1 November 1985)

BERTHEL, R.O., and PLANK, V.G.
Data Reduction Techniques Used in the Determination of Precipitation Rates from Electronic Weight Measurements
Wkshp. on the Correction of Precipitation Measurements, Zurich, Switzerland (1-3 April 1985)

BOEHM, A.R.
Stochastic Dynamic Prediction Using Orthogonal Functions in State Space
Ninth Conf. on Probability and Statistics in Atmos. Sci., Virginia Beach, VA (9-11 October 1985)

BOHNE, A.R., and CHMELA, A.C.
Observations of Turbulence and Aircraft Lightning Strike Events in East Coast Thunderstorms
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

BOHNE, A.R., BOUCHER, R.J. (AFGL); HARRIS, F.I., and RAPP-EDGERTON, D. (SASC Technologies, Inc., Lexington, MA)
The Evolution of Hurricane Gloria during Passage over New England
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

BRENNER, S.
The Effects of Vertical Resolution and Layer Distribution on a Global Forecast Model
7th Conf. on Numerical Weather Prediction, Montreal, Canada (17-20 June 1985)

BURGER, C.F.
A New Model for Specifying Cloud Distributions for Climatologies
Ninth Conf. on Probability and Statistics in Atmos. Sci., Virginia Beach, VA (9-11 October 1985)

CHAMPION, K.S.W.
Middle Atmosphere Models and Comparison with Shuttle Reentry Density Data
COSPAR Mtg., Toulouse, France (30 June-11 July 1986)

COTÉ, O.R., MORRISSEY, J.F., and IZUMI, Y.
Atmospheric Refractivity Structure, Frequency Selective Fading, and Digital LOS Radio Performance
Fourth Internat. Conf. on Antennas and Propagation, Coventry, England (16-19 June 1985)
Atmospheric Refractivity Structure and the Performance of Digital Troposcatter Radio
North Am. Sci. Mtg./Internat. IEEE/AP-S Symp., Vancouver, Canada (18-21 June 1985)
A New Look at Atmospheric Refractive Multipath and the Performance of Digital Radio on Long LOS Paths
URSI Remote Sensing and Communications Mtg. Durham, NH (28 July-1 August 1986)
Atmospheric Refractivity, Multipath, and Digital Radio Performance: Long Paths and Short Paths
IEEE Military Communications Conf., Monterey, CA (5-9 October 1986)
Radio and Radar "Holes" and Multipath Zones: The Global and Local Influences on Atmospheric Refractive Structure and Resulting Adverse Radio and Radar Performance
AGARD Electromagnetic Wave Propagation Panel Symp., Ottawa, Canada (20-24 October 1986)

GLASS, M.
Influence of Condensation Nucleus Concentration on the Mechanism of Precipitation Development in Cumulonimbus
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

GLOVER, K.M. (AFGL); and FORSYTH, D.E. (Natl. Severe Storms Lab., Norman, OK)
Doppler Wind Analysis of Hurricane Gloria
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

GRANTHAM, D.D., and BOEHM, A.R.
The Effect of Viewing Aspect on Climatological Cloud Distributions
Third Internat. Conf. on Statistical Climatology, Vienna, Austria (23-27 June 1986)

HARRIS, F.I. (SASC Technologies, Inc., Lexington, MA); and PETROCCHI, P.J. (AFGL)
Cellular Characteristics as a Severe Storm Indicator
Internat. Un. of Radio Sci. Comm. F. Mtg., Amherst, MA (7-9 October 1985)

HARRIS, F.I. (SASC Technologies, Inc., Lexington, MA); GEOTIS, S. (Massachusetts Inst. of Tech., Cambridge, MA); and BOHNE, A.R. (AFGL)
Dual Doppler Radar Study of Hurricane Gloria
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

HARRIS, F.I. (SASC Technologies, Inc., Lexington, MA); GLOVER, K.M. (AFGL); and SMYTHE, G.R. (SASC Technologies, Inc., Lexington, MA)
Gust Front Detection and Prediction
14th Conf. on Severe Local Storms, Indianapolis, IN (29 October-1 November 1985)
Shear Zone Delineation with Doppler Radar Data
Internat. Un. of Radio Sci. Comm. F. Mtg., Amherst, MA (7-9 October 1985)

KING, J.I.
Differential Inversion and the Limits of Objective Temperature Inferencing
Second Conf. on Satellite Meteorology/Remote Sensing and Applications, Williamsburg, VA (May 1986)

KLEESPIES, T.J. (AFGL); and MCMILLIN, L. M. (NOAA/NESDIS, Washington, DC)
An Extension of the Split Window Technique for the Retrieval of Precipitable Water
Second Conf. on Satellite Meteorology/Remote Sensing and Applications, Williamsburg, VA (May 1986)

KRAUS, M.J.
Battlefield Weather Observation System
Assoc. of Unmanned Vehicle Systems Mtg., Boston, MA (21-23 July 1986)

KUNKEL, B.A.
A Comparison of Evaporation Source Strength Models for Toxic Chemical Spills; The Development of a Dispersion Model to Replace the Ocean Breeze/Dry Gulch Model
JANNAF Safety and Environmental Protection Subcommittee Wkshp. on Atmospheric Transport and Diffusion Modeling, Los Angeles, CA (11-13 June 1985)

LANICCI, J.M., Capt.
An Operational Procedure Using Elevated Mixed-Layer Analyses to Predict Severe-Storm Outbreaks
14th Conf. on Severe Local Storms, Indianapolis, IN (29 October-1 November 1985)
Numerical Simulations of Surface-Layer Flow as Affected by Stability and Vegetation
Seventh Symp. on Turbulence and Diffusion, Boulder, CO (12-15 November 1985)

LANICCI, J.M., Capt., and BOEHM, A.R., Maj.
Detailed Terrain and Vegetation Data Bases Required for Windflow and Microclimate Modeling
Corps of Engineers Wkshp. on Geographic Information Systems in Government, Springfield, VA (10-13 December 1985)

LANICCI, J.M., Capt., KUNKEL, B.A. and WEBER, H.
Evaluation of a Surface-Layer Windflow Model for Complex Terrain Using Meteorological Tower Data from Vandenberg AFB, CA
Flow Modeling Wkshp., JANNAF Interagency Propulsion Committee, Vandenberg AFB, CA (29-30 September 1986); Fifth Joint Conf. on Applications of Air Pollution Meteorology with APCA, Chapel Hill, NC (18-21 November 1986)

MARCOS, F.A.
Requirements for Improved Thermospheric Neutral Density Models
AAS/AIAA Astrodynamics Conf., Vail, CO (12-15 August 1985)
Evaluation of Thermospheric Density Models
NASA/MSFC Workshop on Satellite Drag, Huntsville, AL (November 1985)

MARCOS, F.A., and GILLETTE, D.F.
Satellite Neutral Density Measurements Obtained during the 1984 Equinox Transition Study
GTMS/Equinox Transition Study Wkshp., Cambridge, MA (10-12 July 1985)

METCALF, J.I.
Differential Doppler Velocity Observations in Melting Precipitation
23rd Conf. on Radar Meteor. and Conf. on Cloud Phys., Snowmass, CO (22-26 September 1986)

METCALF, J.I., and GLOVER, K.M.
Twenty-Five Years of Weather Radar in Sudbury, Mass.
AGU Mtg., Baltimore, MD (19-23 May 1986)

MITCHELL, K.E.
A Comparison of Moisture Variables in the Vertical Interpolations of a 4-D Data Assimilation System
7th Conf. on Numerical Weather Prediction, Montreal, Canada (16-21 June 1985)

MORRISSEY, J.F., IZUMI, Y., and COTÉ, O.R.
Atmospheric Measurements and Their Use in a Propagation Model for Troposcatter Radio
URSI Remote Sensing and Communications Conf., Durham, NH (28 July-1 August 1986)

YANG, C.-H.
Energy Calculations for Diagnostics of Global Circulation Simulations
WMO/IUGG Internat. Symp. on Short- and Medium-Range Numerical Weather Prediction, Tokyo, Japan (4-8 August 1986)

ZIMMERMAN, S.P., KENESHEA, T.J., ECKHARDT, R., and VON ZAHN, U.
Analysis of the Bugatti Data for Turbulence Parameters
COSPAR Mtg., Toulouse, France (30 June - 11 July 1986)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

BERTHEL, R.O., and PLANK, V.G.
Time Durations of Rain Rates Exceeding Specified Thresholds
AFGL-TR-85-0122 (24 May 1985), ADA160463

BISHOP, A.W., and METCALF, J.I.
A Multi-Channel Radar Receiver
AFGL-TR-85-0006 (7 January 1985), ADA156058

BOHNE, A.R.
Joint Agency Turbulence Experiment - Final Report
AFGL-TR-85-0012 (21 January 1985), ADA160420
In-Flight Turbulence Detection
AFGL-TR-85-0049 (8 March 1985), ADA160380

BOHNE, A.R., and CHMELA, A.C.
Storm Precipitation and Wind Structure During Aircraft Strike Lightning Events
AFGL-TR-85-0121 (24 May 1985), ADA162338

BOHNE, A.R. (AFGL); and HARRIS, F.I. (SASC Technologies, Inc., Lexington, MA)
Short Term Forecasting of Cloud and Precipitation Along Communication Paths
AFGL-TR-85-0343 (31 December 1985), ADA169744

BURGER, C.F.
World Atlas of Total Sky-Cover
AFGL-TR-85-0198 (4 September 1985), ADA170474

FORSYTH, D.E., Maj., ISTOK, M.J., O'BANNON, T.D. (NEXRAD Joint System Program Office); and GLOVER, K. (AFGL)
The Boston Area NEXRAD Demonstration (BAND)
AFGL-TR-85-0098 (8 May 1985), ADA164426

GROVES, G.V.
A Global Reference Atmosphere from 18 to 80 KM
AFGL-TR-85-0129 (31 May 1985), ADA162499

KUNKEL, B.A.
On the Development of an Atmospheric Diffusion Model for Ground-Level Toxic Chemical Releases
AFGL-TR-85-0338 (20 December 1985), ADA169135

LANICCI, J.M., Capt.
Sensitivity Tests of a Surface-Layer Windflow Model to Effects of Stability and Vegetation
AFGL-TR-85-0265 (25 October 1985), ADA169136

LANICCI, J.M., Capt., AND WEBER, H.
Validation of a Surface-Layer Windflow Model Using Climatology and Meteorological Tower Data from Vandenberg, AFB, California
AFGL-TR-86-0210 (30 September 1986), ADA178480

METCALF, J.I.
Techniques for the Automated Observation of Clouds
AFGL-TR-85-0253 (10 October 1985), ADA165573

MITCHELL, K., and YANG, C.-H.
A Comparison of Moisture Variables in the Vertical Interpolations of a 4-D Assimilation System
AFGL-TR-85-0090 (11 April 1985), ADA160464

MORRISSEY, J.F., IZUMI, Y., and COTÉ, O.R.
Meteorological Measurements on Line-of-Sight Microwave Radio Links
AFGL-TR-85-0299 (22 November 1985) ADA166627
Intercomparisons of Radiosondes and an Airborne Refractometer for Measuring Radio Ducts
AFGL-TR-86-0143 (3 July 1986), ADA175150

MUENCH, H.S., and CHISHOLM, D.A.
Aviation Weather Forecasts Based on Advection: Experiments Using Modified Initial Conditions and Improved Analyses
AFGL-TR-85-0011 (21 January 1985), ADA160369

RIDGE, D., MODICA, G., and JACKSON, A.
A Candidate Mesoscale Numerical Cloud/Precipitation Model
AFGL-TR-85-0252 (10 October 1985), ADA166628

SCHAAF, C.B., 1Lt., WURMAN, J., and BANTA, R.M.
Satellite Climatology of Thunderstorm Initiation Sites in the Rocky Mountains of Colorado and Northern New Mexico
AFGL-TR-86-0075 (31 March 1986), ADA178052

SWEENEY, H.J., and COHEN, I.D., Capt.
Some Microphysical Processes Affecting Aircraft Icing - Final Report
AFGL-TR-85-0100 (8 May 1985), ADA160375

TATTELMAN, P. (AFGL); and WILLIS, P.T. (Atlantic Oceanographic and Meteorological Lab., Miami, FL)
Model Vertical Profiles of Extreme Rainfall Rate, Liquid Water Content, and Drop-Size Distribution
AFGL-TR-85-0200 (6 September 1985), ADA164424

ZIMMERMAN, S.P., and KENESHEA, T.J.
Turbulent Heating and Transfer in the Stratosphere and Lower Mesosphere
AFGL-TR-85-0184 (9 August 1985), ADA166591

CONTRACTOR PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

HOFFMAN, R.N. (Atmos. & Environ. Research, Inc. Cambridge, MA)
A Four-dimensional Analysis Exactly Satisfying Equations of Motion
Mon. Wea. Rev. 114 (February 1986)

KAPLAN, L.D., and ISAACS, R.G. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Retrieval of Humidity Profiles from Satellite Radiance Measurements
Proc. Wkshp. on Advances in Remote Sensing Retrieval Methods (January 1985)

KNUPP, K.R., and COTTON, W.R. (Colorado State University)
Convective Cloud Downdraft Structure: An Interpretive Survey
Reviews of Geophysics and Space Physics 23 (May 1985)

LIOU, K.-N, OU, S., and LU, P.J. (Univ. of Utah, Salt Lake City, UT)
Interactive Cloud Formation and Climatic Temperature Perturbations
J. of Atmos. Sciences 42 (1 October 1985)

LIOU, K.-N (Univ. of Utah, Salt Lake City, UT)
Influence of Cirrus Clouds on Weather and Climatic Processes: A Global Perspective
Mon. Wea. Rev. 114 (June 1986)

NEHRKORN, T. (Atmos. & Environ. Research, Inc. Cambridge, MA)
Wave-CISK in a Baroclinic Basic State
J. Atmos. Sciences 43 (December 1986)

OU, S., and LIOU, K.-N (Univ. of Utah, Salt Lake City, UT)
Cumulus Convection and Climatic Temperature Perturbations
J. of Geophy. Res. 90 (20 February 1985)

WIELER, J.G. (SASC Technologies, Inc., Lanham, MD)
Real-Time Automatic Detection of Mesocyclones and Tornadic Vortex Signatures
J. Atmos. and Oceanic Tech. 3 (March 1986)

ZHENG, Q., and LIOU, K.-N. (Univ. of Utah, Salt Lake City, UT)
Dynamic and Thermodynamic Influences of the Tibetan Plateau on the Atmosphere in a General Circulation Model
J. Atmos. Sciences 43 (1 July 1986)

CONTRACTOR TECHNICAL REPORTS JANUARY, 1985 - DECEMBER, 1986

ECKHARDT, R.J. (OPHIR Corp., Lakewood, CO)
A Sensitivity Study of a One-Dimensional Time-Dependent Warm Cumulus Cloud Model
AFGL-TR-85-0331 (September 1985), ADA170141

FORBES, J.M. (Boston Coll., Newton, MA)
Thermosphere Structure Variations During High Solar and Magnetic Activity Conditions
AFGL-TR-86-0009 (30 September 1985), ADA171350

GALLERY, W.O., HUMMEL, J.R., and FARMER, D.A. (OptiMetrics, Inc., Bedford, MA)
Probability and Conditional Probability of Cumulative Cloud Cover for Selected Stations Worldwide
AFGL-TR-85-0154 (July 1985), ADA162210

GERLACH, A.M. (SASC Technologies, Lanham, MD)
Objective Analysis and Prediction Techniques-1985
AFGL-TR-86-0002 (30 November 1985), ADA169746

HANSEN, D.F., and SHUBERT, W.K. (HSS, Inc., Bedford, MA)
Development, Test and Evaluation of an Automated Present Weather Observing System
AFGL-TR-86-0140 (26 June 1986), ADA172329

HAYENGA, C.O. (New Mexico Inst. of Mining and Technology, Socorro, NM)
Airborne Lightning RF Direction Finding: A Feasibility Study
AFGL-TR-85-0311 (November 1985), ADA173867

ISAACS, R.G., and DEBLONDE, G. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Water Vapor Profile Retrievals at 183 GHz: Land vs. Ocean and Clear vs. Cloudy
AFGL-TR-85-0095 (1 May 1985), ADA170033

ISAACS, R.G., BARNES, J.C., PETRO, L.D., and WORSHAM, R.D. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Intercomparison of DMSP OLS, NOAA AVHRR, GOES VISSR, and Landsat MSS Imagery for Cloud Property Determination: Recommendations for Digital Data Analysis
AFGL-TR-86-0012 (18 January 1986), ADA169285

ISAACS, R.G., DEBLONDE, G., WORSHAM, R.D., and LIVSHITS, M. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Millimeter Wave Moisture Sounder Feasibility Study: The Effect of Cloud and Precipitation on Moisture Retrievals
AFGL-TR-85-0040 (8 March 1985), ADA162231

KAO, C.Y., and OGURA, Y. (Univ. of Illinois, Urbana, IL)
A Cumulus Parameterization Study with Special Attention to the Arakawa-Schubert Scheme
AFGL-TR-85-0159 (June 1985), ADA166801

KAPLAN, L.D., LOUIS, J.-F., HOFFMAN, R.N. ISAACS, R.G., GUTOWSKI, W.J., and NEHRKORN, T. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Improving Numerical Weather Prediction by Maximizing the Use of Assimilated Satellite Data
AFGL-TR-85-0298 (20 December 1985), ADA169295

LORENZ, E.N. (Ctr. for Meteorology and Physical Oceanography, Cambridge, MA)
Experimental Runs with a Low-Order Model of a Moist General Circulation
AFGL-TR-85-0118 (31 May 1985), ADA160359

NELSON, L.D., HANSON, K.R., WURMAN, J.M., and ECKHARDT, R.J. (OPHIR Corp., Lakewood, CO)
Cloud Microphysics Analysis and Modeling
AFGL-TR-86-0179 (July 1986), ADA175489

NICKERSON, E.C. (ERL/NOAA, Boulder, CO)
A Three-Dimensional Mesoscale Model for the Simulation of Clouds, Precipitation and Airflow
AFGL-TR-85-0307 (31 October 1985), ADA164468

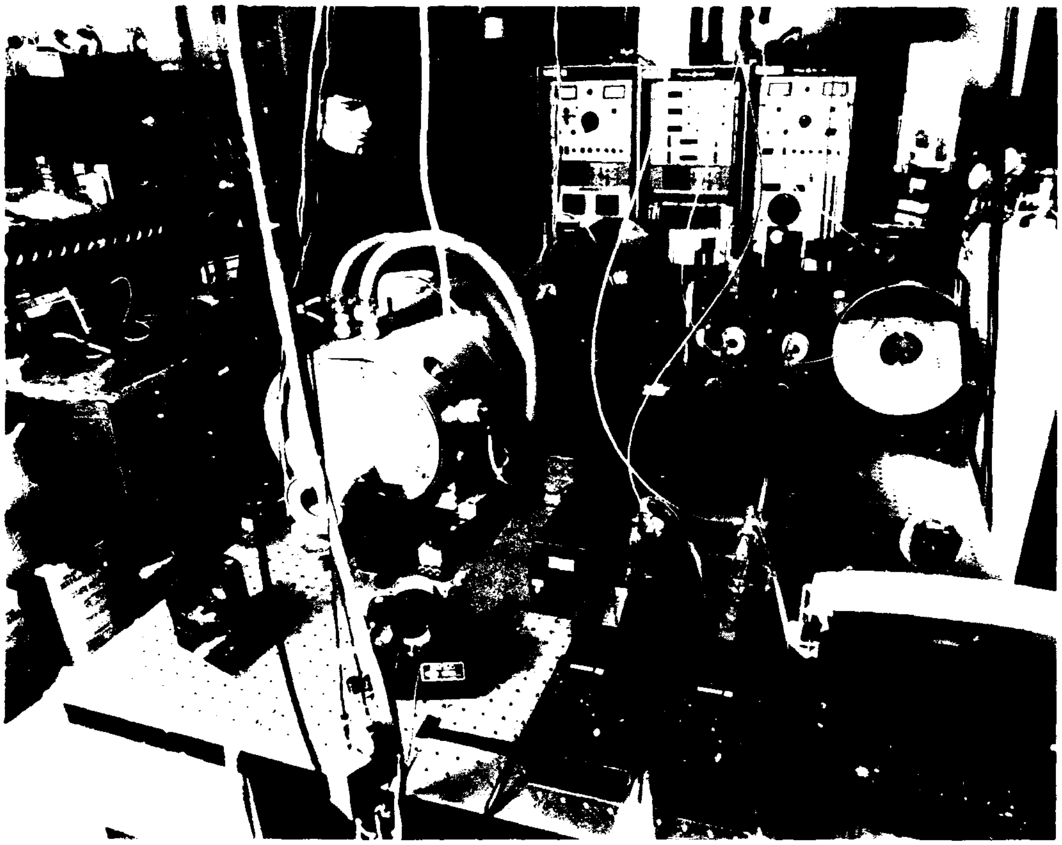
NORQUIST, D.C. (SASC Technologies, Inc., Lanham, MD)
Alternative Forms of Moisture Information in 4-D Data Assimilation
AFGL-TR-86-0194 (15 September 1986), ADA179792

SEITTER, K.L. (Univ. of Lowell, Lowell, MA)
The Specification of Lateral Boundary Conditions in Three-Dimensional Mesoscale Numerical Models
AFGL-TR-86-0005 (1 October 1985), ADA165279

SOONG, S.T., OGURA, Y., and KAU, W.S. (Univ. of Illinois, Urbana, IL)
A Study of Cumulus Parameterization in a Global Circulation Model
AFGL-TR-85-0160 (June 1985), ADA170137

TUNG, S.-L. (Systems and Applied Sciences Corp., Vienna, VA)
Users Guide for Normal Mode Objective Analysis of Global Data Assimilation
AFGL-TR-85-0042 (1 March 1985), ADA160373

WURMAN, J. (OPHIR Corp., Lakewood, CO)
A Plotting Library for Tektronix Compatible Devices
AFGL-TR-86-0014 (8 August 1985), ADA173985



High-Power Electron Beam Injection CO_2 TEA Laser Under Development at AFGL. (This laser will act as the transmitter in a coherent, Doppler wind-sensing system to provide meter-per-second wind velocities out to a range of 30 km. Such a lidar system has application to design criteria for electro-optical systems performance, to the detection of wind shear and low level turbulence, and to the determination of local wind patterns over complex terrain.)

V OPTICAL PHYSICS DIVISION

The task of the Optical Physics Division is to expand and exploit knowledge of the optical and infrared properties of atoms, molecules, and particulates in the earth's atmosphere, in the celestial and zodiacal backgrounds, and in plumes from rockets and space vehicles. With this knowledge, Air Force systems can effectively penetrate the environment to locate, communicate with, track, or destroy desired targets and avoid false targets. They can also measure and predict the natural and disturbed conditions of the atmosphere that influence optical and infrared propagation. Research consists of basic analysis and compilation of atomic, molecular, and particulate properties using laboratory studies, theoretical developments, and actual verification in field tests. Lidar techniques are important emerging tools being developed at AFGL for ground and space measurements. Satellite and rocket observations of the celestial, spectral, and spatial infrared emissions are essential to this program.

The goal of the research is to develop "tools" to be used directly in the design, testing, and actual operation of Air Force and DoD systems. These tools include various data bases, models, and computer codes friendly to the developers of new systems and capable of easy and rapid interrogation by operations officers. Some of the specific tools are the LOWTRAN and FASCODE transmission and radiance codes, the HITRAN molecular data base, celestial background models, atmospheric turbulence models, and models of the aerosols and infrared radiating molecules in the atmosphere. The portion of the electromagnetic spectrum studied extends from 200 nm in the ultraviolet to 1 cm, where the far infrared blends into the microwave radio spectrum. The research in the Division includes studies of: the visible and near visible properties of the atmosphere, where aerosol and molecular scattering is the predominant mechanism of attenuation; the infrared properties of the atmosphere, generally where thermal equilibrium usually prevails; and the infrared properties of exoatmospheric sources—stars, nebulae, and zodiacal dust. Improved techniques for spectroscopic, lidar, and scattering measurements are also developed.

A major area of investigation by the Division concerns atmospheric attenuation, or transmission and scattering of radiation by the atmosphere, including laser beams. Atmospheric molecules absorb optical and infrared radiation selectively at discrete wavelengths. Extensive computer programs have been developed which make use of the vast collection of spectroscopic data for molecules (*AFGL Atmospheric Absorption Line Parameters Compilation HITRAN Database*) and which permit the calculation of this transmission, both for laser beams and the emission and transmission of radiation from hot gases and plumes. Detailed atmospheric absorption curves and tables for high resolution and laser transmission are available. The well-known LOWTRAN atmospheric transmission computer code is used for determining the low-resolution (approximately 20 wave-numbers) transmission of the atmosphere for a wide range of tactical weapon-delivery problems under various meteorological conditions. The codes have been designated as the standard atmospheric codes for both the Department of Defense, as part of the DoD transmission program, and for the international research community, as part of the Technical Coordination Program and the International Radiation Commission.

Scattering by aerosols and molecules in the atmosphere also contributes both to attenuation and to reduction in the contrast of a target seen through the atmosphere.

During July, 1985, the new Transportable Optical Atmospheric Data System (TOADS) field site, in Sudbury, Massachusetts, became operational. This site consists of four pads located on a 987 meter test range. The TOADS vans are located on pads one and four. Instruments can be installed and operated from pad two, located 300 meters from pad one, or pad three, located 500 meters from pad one. This test facility is used to take measurements of the influence of adverse weather (snow, fog, haze) on electromagnetic propagation. (For a more detailed description see "Atmospheric Aerosols" below.)

The results of these measurements and models are applied to target acquisition and detection problems as, for example, a Tactical Decision Aid (TDA) to describe the impact of the natural environment on air-to-ground infrared-guided weapon systems (maximum lock-on range), and also to laser propagation studies.

Turbulence in the atmosphere leads to laser-beam fluctuations in flux distribution, coherence, and direction as the laser beam propagates through that atmosphere. Efforts are under way to measure and model the altitude and temporal variations in the index of refraction of the air, the most important parameter in determining these effects.

A powerful technique for remotely determining the optical and meteorological parameters and composition of the atmosphere from the ground or space is through the use of a lidar, which measures the transit time and intensity of the light scattered back from a laser pulse at one or more wavelengths. Different lidar techniques will be exploited, including molecular and aerosol scattering, resonance fluorescence, Raman, Doppler, and DIAL (Differential Absorption Lidar).

Similarly, infrared backgrounds against which a target must be located are a major concern of the Division efforts. Such emissions from the atmosphere or celestial sky represent interfering background noise superimposed on the optical/infrared target signatures that a surveillance system may be trying to detect. An inseparable part of these measurements is the development of very sensitive, advanced cryogenically cooled infrared sensors and spectrometers. A high-resolution, cryogenically cooled Fourier interferometer has been flown on a balloon to observe infrared atmospheric emission. The infrared emission of the lower atmosphere can be calculated from computer programs such as those discussed above. The infrared emission from the upper atmosphere has been measured by using a balloon-borne cryogenically cooled interferometer-spectrometer, and emission from the earth limb was detected by a rocketborne cryogenic long wave length infrared sensor.

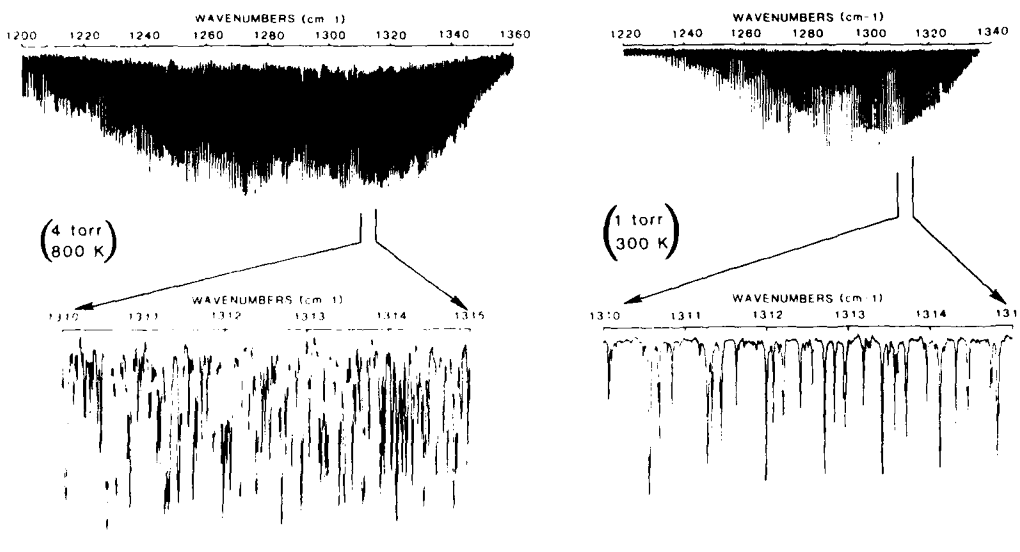
MOLECULAR SPECTROSCOPY

HITRAN Database: The HITRAN molecular absorption database is a compilation of spectroscopic parameters from which a wide variety of computer simulation codes are able to calculate and predict the transmission and emission of radiation in the atmosphere. This database is a prominent and long-running effort established by the Air Force at AFGL in the late 1960's in response to the requirement for a detailed knowledge of infrared transmission properties of the atmosphere. With the advent of sensitive detectors, lasers, rapid computers, and higher resolution spectrometers, a large database representing the discrete molecular transitions that affect radiative propagation throughout the electromagnetic spectrum became a necessity. The HITRAN database has been periodically updated and expanded to meet new Air Force requirements through programs directed through the Optical Physics Division.

The most recent edition of the HITRAN database became available in late 1986. This latest version now incorporates data on twenty-eight molecular species with bands covering regions from the millimeter through the visible portion of the spectrum. Originally the database contained for each molecular transition the basic parameters of: (1) resonant frequency; (2) line intensity; (3) air-broadened halfwidth; and (4) lower state energy (as well as unique quantum identifications). Additional parameters have recently been provided which permit new capabilities for remote sensing in the atmosphere and capabilities to deal with non-local thermodynamic effects in the upper atmosphere. The overall structure of the database has been expanded to include files of cross-section data on heavy molecular species such as the fluoro-chloro methanes and oxides of nitrogen which are not yet amenable to line-by-line representation. This has added to HITRAN the capability of qualitative detection of man-made gases in the "window" regions of the infrared. On-going research efforts will gradually move this data to the main body of the database. Presently over 340,000 transitions are given on the high-resolution portion of HITRAN.

High-Resolution Laboratory Spectroscopy: The AFGL High Resolution Fourier Transform Spectrometer (FTS) has recently undergone a major modification to extend its spectral coverage to longer wavelengths. It is now capable of observing transitions down to about 550 cm^{-1}. Previously the spectral range was between 1600 and 5000 wavenumbers. The new capability, coupled with modifications to the high temperature cell, allows the observation of highly excited rotational levels of vibration-rotation bands not previously measured under controlled conditions. This unique laboratory setup is providing data on the important lower mode vibrational bands and their sequence "hot bands" that will significantly improve the models used for long path transmittance, laser propagation, remote sensing, and plume simulation. The results from the AFGL FTS are used to determine energy levels that enhance and improve the AFGL HITRAN molecular database. Initial spectra taken include the bending mode vibration of deuterated water vapor, and the symmetric stretch vi-

HIGH-RESOLUTION (0.006 cm^{-1}) N_2O SPECTRA

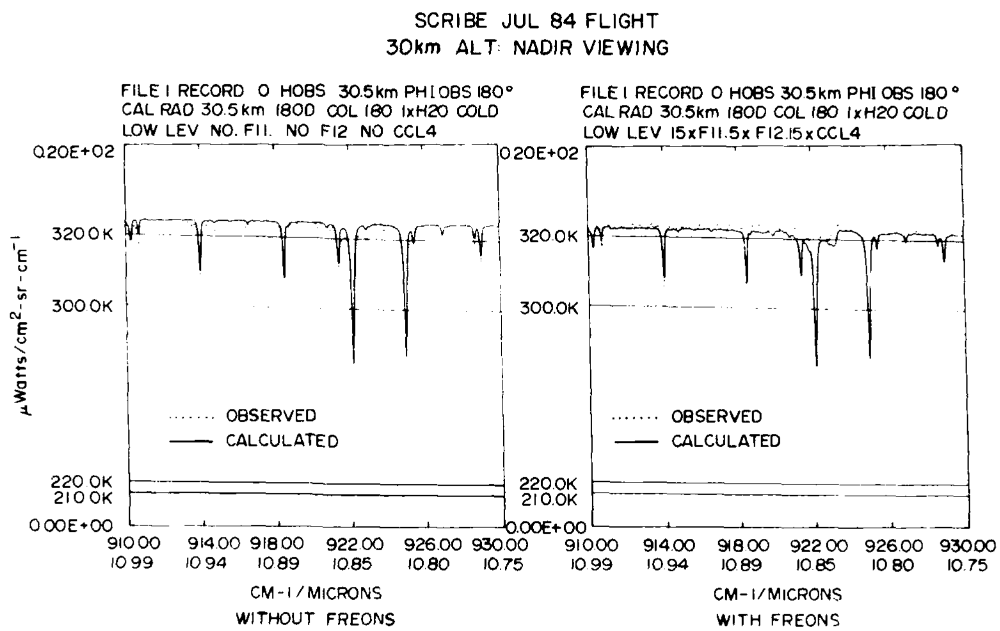


AFGL TWO-METER OPD INTERFEROMETER

Spectra of N_2O at 800°K and Room Temperature.

bration region of nitrous oxide. The figure illustrates two spectra of N_2O, one taken at room temperature and the other at the elevated temperature of 800° K, with an enlargement of portions of the spectra. The line position precision is 0.0003 cm^{-1} for well-isolated lines. Preliminary analysis of the latter measurements demonstrates that there will be considerable extension of the knowledge of the energy levels and potential function of nitrous oxide. This has direct application to simulating hot plumes, but also in forming the foundation for a unified treatment of the molecule such as has been carried out for carbon dioxide. Application of the instrument to the 15 mm bands and associated hot bands of CO_2 is also expected to be a major contribution.

High-Resolution Spectroscopic Field Measurements: The Stratospheric Cryogenic Interferometer Balloon Experiment (SCRIBE) had a most successful flight from Holloman AFB on August 10, 1986. Major modifications to the package were undertaken for this flight with the additional support of an outside agency. A telescope operating at ambient temperature and ground-controlled steering mirror were added along with a bore-sighted television camera. An operator viewing a television monitor could control the view by manipulating a joystick. This was the first time that visual data along the direction of viewing have been taken on such a high-resolution, high-altitude experiment and recorded on video tape. The balloon on this flight reached a float altitude of 76 kft, and a large number of horizontal and nadir scans from the interferometer were



Analysis of Data from Stratospheric Cryogenic Interferometer Balloon Experiment (SCRIBE), 1984.

obtained. Along with the data from the 1983 and 1984 flights, a major program is underway to analyze the results. Analysis of the previous two flights has demonstrated the excellent achieved sensitivity and resolving power achieved with SCRIBE. The first-ever detection of CCl_2F_2 (F12) in the nadir-viewing direction is one such example of the superb sensitivity achieved (see accompanying figures). The results reported on the strong nitric acid bands at 11μ and their subsequent addition to the HITRAN molecular database have been examples of simulations for atmospheric profile retrieval. Likewise, there have been impressive spectra of the fluoro-chloro methanes, F11 and F12. The 1983 flight, due to a leak in the balloon, took a number of nadir-viewing spectra. These spectra show deficiencies in the present modeling capabilities which are now being researched. High quality spectra from the most recent flight, improved by the narrower field-of-view now available, are expected to be of extreme value. Future flights will be aimed at observations of photo-chemically active constituents.

Molecular Line Shape and Continuum: Currently, the issue limiting the accuracy of the calculation of atmospheric transmittance and radiance due to molecular absorption is the knowledge of the collisional line shape. The absorption profile near line center is well described by the impact approximation (Lorentz line profile). However, a correct description of line wing absorption must take into account the finite duration of collision. The continuum absorption and radiance observed for atmospheric paths results from the overlapping of line wings far from line center and requires an accurate description of the physics of the collision. Three research efforts are currently being pursued in the area of molecular line shape: (1) a theoretical effort to study the details of binary collisions (emphasis on water-water interactions); (2) the development of a formalism to accurately account for line coupling effects (emphasis on carbon dioxide-nitrogen collisions); and (3) an experimental program to validate line coupling and line wing effects in carbon dioxide. A resolution of these issues is required for applications including atmospheric radiative transfer, long path (20 km) transmittance in the atmosphere, and remote sounding of the atmosphere.

ATMOSPHERIC TRANSMISSION

The atmospheric transmission of electromagnetic radiation in the ultraviolet, visible, infrared, and millimeter wave region is affected by molecular absorption and scattering and by extinction from particulates (dust, haze, fog, rain) in the atmosphere. The relative importance of these different attenuation processes depends on the wavelength of the radiation and the atmospheric conditions.

In a cloud (fog)-free atmosphere, molecular absorption dominates the infrared and millimeter regions of the spectrum, whereas aerosol extinction dominates the visible part of the spectrum. This domination is not complete, however, and a full understanding of atmospheric propagation requires that we deal with the appropriate molecular and aerosol effects at all wavelengths. Molecular absorption is highly wavelength-dependent, whereas aerosol extinction varies much less with wavelength. In the infrared, molecular absorption tends to determine the "windows" within which atmospheric propagation is possible, but the transparency within these windows tends to be determined by the molecular "continuum" and aerosol effects. As a result, aerosol and cloud attenuation can be the critical factors not only for visible wavelengths but also for infrared radiation in the window regions.

Aerosol and cloud-drop attenuation can affect radiation propagation in several ways. Particulate scattering and absorption along with molecular attenuation reduce the intensity of a beam of radiation as it travels along an atmospheric path and thereby become factors in determining beam transmittance. For many applications, such as laser beam propagation, we are not only concerned with the extinction loss in a beam of radiation but also with the temporal and spatial intensity variation due to turbulence and the angular distribution of the radiation scattered out of the direction of propagation of the direct (incident) beam. One of the most important effects of this scattered radiation is the reduction of contrast in imaging systems at the visual and near infrared wavelengths. The scattered light from the sun forms the background sky radiance against which objects may have to be viewed and detected.

The attenuation by atmospheric molecular constituents is a complex and highly variable function of wavelength due to the numerous rotation and vibration-rotation transitions and molecular line shapes. In addition, model predictions of molecular attenuation depend strongly on the amount of absorbing gas itself and the temperature, pressure, and density of other line-broadening gases along the atmospheric path.

The optical effects of particulate matter, especially those of haze and dust particles, are not only a function of particle concentration, but also of particle size, shape, chemical composition, and physical structure. Although they have a much weaker spectral dependence than molecular absorption, the aerosol optical properties are highly variable with air mass, weather conditions, and location. Because of the extreme variability of these properties, it is more difficult to develop accurate models for the optical/infrared effects of aerosols and droplet clouds.

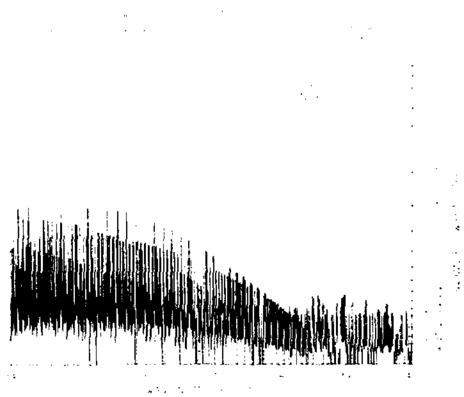
The final goal of this research in the Optical Physics Division has been the development of computer codes which allow an efficient and accurate calculation of these various atmospheric propagation properties for application to Air Force systems and operations.

Atmospheric Transmittance and Background Radiance Models: The atmospheric transmittance and background radiance modeling program focuses on the absorption and scattering properties of the molecular and aerosol constituents of the earth's atmosphere and their effects on radiation propagating through it. In addition, adverse weather effects, such as fogs, clouds, rain, and snow, are included in the program. Two different models for predicting the transmission and radiative properties of the atmosphere for low and high spectral-resolution applications have been developed: LOWTRAN (Low Resolution Transmission) and FASCODE (Fast Atmospheric Signature Code). Both models utilize similar representative model atmospheres, aerosol models, slant-path refractive geometry, and diffuse and continuum absorption models. The models differ in their spectral resolution, spectral range, and computational speed of calculation.

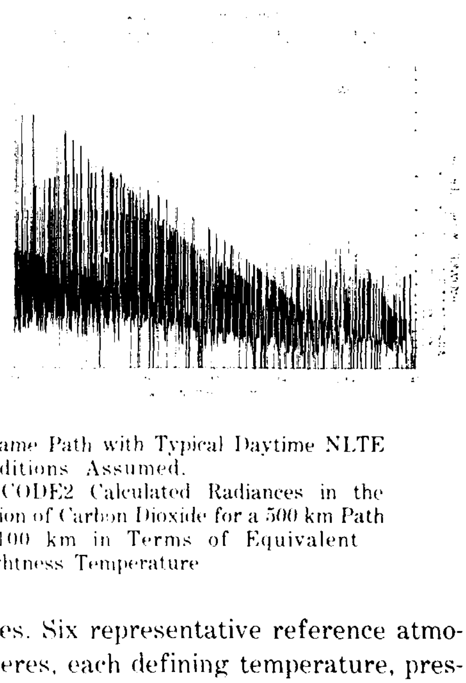
LOWTRAN predicts atmospheric transmittance, background radiance, and scattered solar radiation at a fixed spectral resolution (20 cm^{-1}) and covers the spectral region from the near ultraviolet to the mid-infrared. It provides a simple and computationally rapid means of estimating the atmospheric effects on broadband radiation with an accuracy adequate for many applications. The current version of the code, LOWTRAN 6, includes improved water-vapor continuum and aerosol models, rain and cirrus cloud models, as well as the contribution to the sky radiance of single scattered solar/lunar radiation.

FASCODE has been developed for the computation of atmospheric transmittance and radiance using the line-by-line method. This model is applicable to spectral regions from the microwave to the near ultraviolet. An algorithm for the accelerated convolution of line shape functions (Lorentz, Voigt, Doppler) with spectral line data is used for the high resolution predictions. These calculations are made at a variable sampling interval based on the average spectral line width appropriate to each layer in the atmosphere. The present version of the code, FASCODE 2, addresses the effects of atmospheric molecular, aerosol, and hydrometeor constituents on propagation radiation. Non-local thermodynamic equilibrium (see the figure) and the inclusion of diffuse spectral contributions (ultraviolet and visible ozone absorption, aerosols, rain, and clouds) are model options. Applications of the code include laser propagation, plume signature propagation, and background radiance simulations. Systems applications are facilitated by the availability of laser options, weighting function calculations, and instrumental filter and scanning functions.

An atmospheric database (AFGL-TR-86-0110) of volume mixing ratios (from ground to 120 km) for twenty-eight minor and trace gases has been assembled for use with the radiance-transmittance

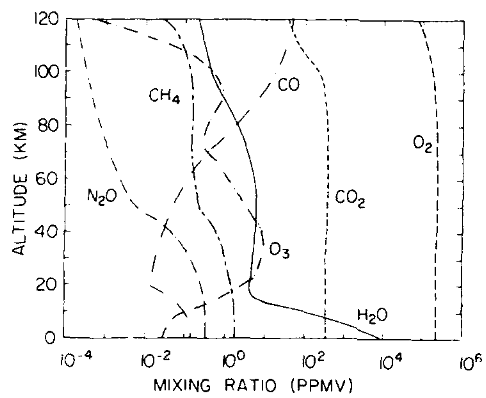


a. LTE Assumed with Kinetic Temperature of 210°K.



b. Same Path with Typical Daytime NLTE Conditions Assumed.
FASCODE2 Calculated Radiances in the Region of Carbon Dioxide for a 500 km Path at 100 km in Terms of Equivalent Brightness Temperature

codes. Six representative reference atmospheres, each defining temperature, pressure, and density as a function of altitude, provide a range of climatological choices. Analogous zonal-mean profiles for the major radiatively active constituents have been adapted from satellite data and dynamical-photochemical analyses (see the figure). The remaining species are defined by single profiles appropriate for U.S. Standard conditions.



Constituent Volume Mixing Ratios Associated with U.S. Standard Atmosphere.

New features to be included in future updates of the codes are the contribution of multiply scattered radiation to the background radiance calculations in both LOWTRAN and FASCODE, more accurate band-model parameters for the LOWTRAN model, and the addition of the ultraviolet absorption bands of molecular oxygen.

Atmospheric Aerosols: To better understand the properties of the atmospheric aerosols and their effects on the propagation of radiation of all wavelengths from the ultraviolet through the microwave spectral regions, laboratory and theoretical studies of aerosols are ongoing.

Size distribution, concentration, shape, and composition determine the optical and infrared effects of aerosols. The influence of large temporal increases of the aerosol concentration on radiation and climate, both by smoke generated at the ground and by volcanic aerosols spreading globally in the lower stratosphere, is currently a matter of concern.

Laboratory investigations have centered on the optical and physical properties of particulates from simulated forest fires. The Defense Nuclear Agency was interested in the optical constants of such aerosols for use in models of the climatic effects of smoke generated by raging firestorms, as in the Nuclear Winter problem. The Flying Infrared Signatures Technology aircraft operated by the Infrared Technology Division provided data from a recent forest fire. In addition, there were ground-based observations and measurements on a clear autumn day in 1984 of a streaked aerosol layer coming from Montana forest fires which posed interesting questions. The most important was why the particles observed here were much larger than those ordinarily seen. Hindrance of cloud-droplet growth by overseeding in the rising, supersaturated smoke plumes appears to have fostered intense coagulation of the wetted smoke particles. Evaporation at the top of the smoke column would then have released only a small number of very large smoke particles.

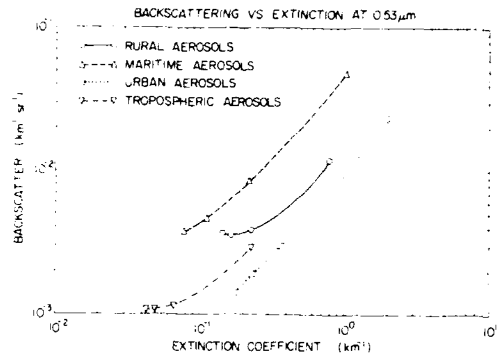
With regard to stratospheric aerosols, the Laboratory evaluated a long series of visual measurements of neutral points of sky polarization, which began in 1968. The eruption in Mexico of El Chichon in April, 1982, resulted in a large increase of the distance of the Babinet and Arago neutral points from the sun and the anti-sun, respectively. The data of this period, where the properties of the stratospheric aerosol are well known, are expected to permit better interpretation of the large historical record of neutral-point measurements which goes back to about 1886. For example, a special optical occurrence at, and after, sunset was measured at Hawaii soon after the El Chichon eruption. It was very likely related to a very high and dense aerosol layer. In our latitude (42° N), this feature was observed a year later. It was absent after the strong eruptions of 1902 and 1911.

One of the major results of the theoretical studies of the atmospheric aerosols and particulates is the development of models which describe their properties. These models include spatial variations of the particle properties, both with geography and with altitude. The models for the boundary layer, which represent rural, urban, and maritime environments, include a dependence on the relative humidity and, in the case of the maritime aerosol model, on the prevailing wind speed. The aerosol models for the stratosphere allow for the effects of recent volcanic eruptions, which sometimes inject significant quantities of dust and gases into the stratosphere. There are also models for different types of clouds, fogs, and precipitation. These models were recently extended to cover the entire spectral range from the ultraviolet through the microwave, in the process of adding them to the FASCODE program. One of the primary applications of the aerosol and particulate models is in the atmospheric transmittance/radiance codes LOWTRAN and FASCODE. However, these models are also used for such applications as simulation studies of lidar measurements, or in analyzing data from some of the field experiments. A modified version of some of these aerosol models served as the basis of the aerosol models incorporated in the "Standard Atmosphere for Radiation Computation" developed by the International Association for Meteorology and Atmospheric Physics.

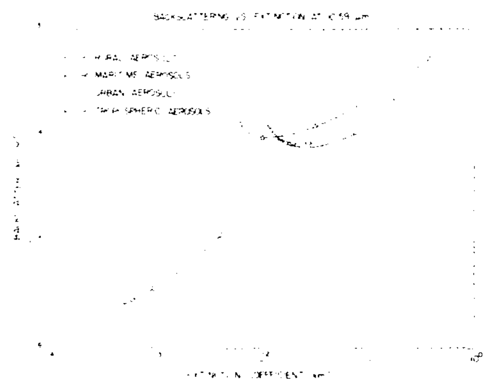
Research studies in this area have led to the development of an improved method for the inversion of measurements of the radiation scattered by aerosol particles as a function of angle, to determine the size distribution of the particles. In addition, research has recently been initiated to develop a global climatology of the atmospheric aerosols to aid in the process of determining which of the aerosol models best represents the atmospheric conditions at a given time and location.

There is still a serious gap in our knowledge of aerosol optical/infrared effects, especially in the planetary boundary layer, the well-mixed layer immediately adjacent to the ground, under marginal-to-poor weather conditions: heavy haze, fog, snow, rain, and low clouds. To fill this data gap and, at the same time, provide a flexible mechanism for responding to other data needs, a mobile optical/infrared laboratory has been developed. This laboratory, the Transportable Optical Atmospheric Data System (TOADS), consists of two instrumented trailers housing numerous instruments controlled by microcomputers. The trailers are normally located at the Sudbury test facility (see the figure.)

Spectral radiance and irradiance measurements in the visible and near infrared (0.35-1.2 μm) are made with four grating spectrometers controlled by a microcomputer from one trailer. High-resolution spatial and temporal profiles of relative aerosol backscatter are taken with the lidar installed on the top of the second trailer in a gimballed mount. The aerosol backscatter profiles are inverted to obtain the range-resolved extinction coefficient. In addition, this trailer houses the lidar control and data logging system, and the



a. 0.53μm



b. 10.59μm

Aerosol Backscattering Versus Extinction for Two Laser Wavelengths, Based on Calculations Using the AFGL Aerosol Models. (The curves show the changes for a given type of aerosol with changing relative humidity while holding the number densities constant for the different aerosol models (Rural: 15,000 particles per cm^3 Maritime: 4,000 particles per cm^3; Urban: 20,000 particles per cm^3; Tropospheric: 5,000 particles per cm^3. The symbols along each curve from left to right correspond to relative humidities of 0, 70, 80, and 99 per cent (with increasing extinction).

PC/AT microcomputers for instrument control, data logging, and real-time data analysis. Both trailers are equipped with standard meteorological sensors.

Aerosol size distributions and concentrations in the range from 0.002 to 20 μm are made with commercially available aerosol probes. Raindrop size distributions and concentrations in the range from 200 to 12,400 μm are measured with a PMS rain spectrometer. Snow and rain rates are measured using an automated tipping bucket system developed by the Laboratory. The aerosol scattering characteristics can be determined by the multiangle visible nephelometer, the dual wavelength (1.06 and 10.6 μm) polar nephelometer, or the Abridged Polar Nephelometer (APN). This instrument can make measurements at five wavelengths (0.325 μm, 0.65 μm, 0.95 μm, 2.25 μm, and 10.6 μm) and three scattering angles (30°, 110°, and 140°).

A new ultraviolet forward scatterometer has been developed and tested. The forward scatterometer makes high angular resolution measurements of the aerosol phase function in the solar-blind ultraviolet region for scattering angles of 1° to 10°. This information is inverted to obtain the aerosol size distribution in the 0.1 to 10 μm range. Three new HSS, Inc., instruments measure visibility. An infrared transmissometer determines transmittance in the 2-14 μm wavelength region, while a visible transmissometer measures transmittance in the 0.55 μm range. The transmissometers can be used in a slant path configuration, by means of a specially developed, folded path visible/infrared transmissometer and a retroreflector mounted on a tethered balloon or a tower, to obtain simultaneous measurements of the total visible and infrared extinction along the path.

The TOADS system has been used during the past few years to conduct measurements under a variety of atmospheric conditions (clear, rain, fog and snow) in support of sensor tests for the Air Force (Foreign Technology Division) and the Sandia National Laboratory and U.S. Army Cold Region Research and Engineering Laboratory. The atmospheric transmission and propagation measurements performed with TOADS not only contribute to a better understanding and modeling capability of atmospheric effects, but also make it possible to assess the performance capabilities of operational electro-optical and infrared sensors in different weather conditions.

AFGL managed and conducted field measurements to support the ASD/IRST program in conjunction with the First International satellite cloud climatology project Regional Experiment (FIRE) at Madison, Wisconsin. This program investigated the influence of optically thin cirrus clouds on long path transmission. The data consist of measurements from four ground-based lidars, two rawinsonde sites, a sun photometer, and lidar and radiometric data from a high-flying aircraft (NASA's ER-2). In addition, variable pathlength transmission measurements at cirrus cloud altitudes in the 3-5 μm spectral range were made with the FLIR aboard the AFGL NKC-135 with a SAC B-52 as a target. Measurements of the aerosol size distributions and the concentrations along the flight path were taken with the K band radar and 1-D and 2-D PMS probes on the Aeromet Lear jet.

OPTICAL TURBULENCE

The Atmospheric Optics Branch is engaged in measurements, analysis, and modeling of turbulence as it influences the propagation of an optical/infrared beam in the atmosphere. Air Force and Strategic Defense Initiative (SDI) optical systems being planned for future inventory will be affected to various extents by turbulence. High-energy laser beams as well as guidance, control, communications, and imaging systems all are subject to turbulence wave distortion. Turbulence effects are encountered in every day experience in the shimmering of city lights as seen from a hilltop on a warm summer night or the twinkling of stars. Turbulence-induced scintillation is one effect that can cause loss of information or signal distortion of a beam. Many other optical turbulence effects impact the performance of infrared, visible, or ultraviolet laser systems, such as image "dancing" and beam wander.

The most important parameter used to describe the effects of atmospheric turbulence is the index of refraction structure constant, C_n^2. System design criteria are in turn defined by parameters deduced from C_n^2. Some of the limitations imposed by C_n^2 can be partially or fully overcome by compensated imaging techniques or adaptive optics; however, the turbulence strength must be known to apply effective compensation techniques. The ability to measure or forecast turbulence conditions is thus needed to assess or predict levels of degradation.

AFGL has developed a wide range of capabilities in measuring and analyzing optical turbulence. Particular sites have been characterized for turbulence conditions and laser system performance. The database of C_n^2 profiles has been used to calculate and analyze the particular turbulence parameters needed by system designers. This database has also been used to provide empirical models of C_n^2 profiles to system or experiment designers for assessing or modeling system performance. AFGL measurements have provided data on atmospheric propagation conditions for system or experiment diagnosis in several measurement programs. All these areas of direct support of Air Force and SDI programs are complemented by the in-house research effort. This effort is pursuing an understanding of the nature of atmospheric turbulence, its models and its various effects on optical systems. Gravity, or buoyancy, waves as a generation mechanism of turbulence is an ongoing research topic. The relationship between optical and mechanical turbulence is under investigation through analysis of measurements. Both these research efforts seek to clarify the nature of optical turbulence, but also support the larger effort of modeling or forecasting. This modeling has a broad scope, including short-term forecasts and climatological models as well as models based on meteorological or synoptic conditions. Finally, the modeling of the total atmospheric effect on laser beam propagation is under development. This includes the computer simulation, via a wave optic propagation code, of the effects of turbulence and thermal blooming and is a natural extension of the atmospheric transmission codes developed by Optical Physics Division scientists.

AFGL turbulence measurements have been made for the Air Force Weapons Laboratory, the Rome Air Development Center, and M.I.T./Lincoln Laboratory. Research efforts have also been coordinated with the Strategic Defense Initiative Organization, the Army Atmospheric Sciences Laboratory, the Air Force Weapons Laboratory, the Air Weather Service, Space Division and other DoD organizations to determine Air Force requirements and to plan measurement, analysis, and modeling activities. Measurements have been performed in conjunction with scientists from Army and Navy laboratories, as well as university researchers. The AFGL measurements have provided atmospheric data in support of programs for the Strategic Defense Initiative Organization and Space Division. The technology and instrumentation developed in measuring atmospheric turbulence have been transferred to assist other programs (AFWL, DARPA). The AFGL expertise in atmospheric effects has been recognized and has resulted in personnel acting as consultants to major Air Force and SDI programs, such as the Integrated Test Uplink Experiment, the Free Electron Laser, and the Relay Mirror Experiment.

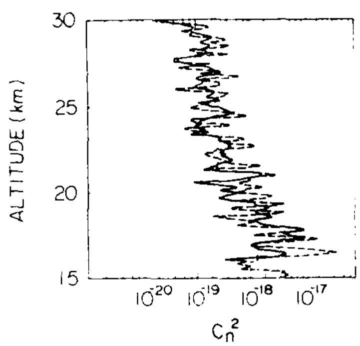
Measurements: The thermosonde provides AFGL with unique capabilities for making in-situ turbulence measurements from the ground up to 30 km with high spatial resolution and relatively low cost. The thermosonde consists of microthermal fine wire thermometry instrumentation packaged with a radiosonde. It is carried aloft by a balloon. As the 6 foot balloon ascends from ground level to about 30 km, the atmospheric temperature is sampled simultaneously at two points about 1 meter apart. The difference in temperature is detected, filtered, and amplified by a sensitive Wheatstone bridge and synchronous detector circuit. Radio transmission of the differential temperature measurement, along with other meteorological variables, is broadcast by digital radiosondes. A ground-based computer converts the signals into C_n^2 and stores the data as functions of altitude. Most of our turbulence measurements have been made with this instrument. Progress is continuing to refine the instrument, reduce its cost, and to understand and eliminate possible error sources in the measurements, in particular, the influence of daytime solar radiation on the differential resistance of the wire probe. Other turbulence measurements have been obtained from the AFGL stellar scintillometers which measure scintillations, or fluctuations in the intensity of a star at various spatial frequencies using a 36 cm aperture telescope. Telescope and spatial weighting functions are applied to the data to obtain C_n^2 as a function of altitude. This instrument provides C_n^2 values at seven altitude points from approximately 2 km to 18 km. The AFGL scintillometer is continually being refined for ease of calibration and operation at remote field sites.

The thermosonde and scintillometer complement one another in that the thermosonde obtains high-resolution data (20m) in the timeframe of the balloon ascent (about 1½ hours), and the scintillometer takes "snapshot" profiles of turbulence but with rather low altitude resolution (kilometers). Additional data have been obtained by mesospheric-stratospheric-tropospheric radar, Doppler radar, and other specialized optical instrumentation.

To clarify the relationship of the jet stream and optical turbulence, a measurement campaign was undertaken at the Pennsylvania State University in late April, 1986. This program involved AFGL thermosondes and scintillometer, personnel from AFWL, RADC, and the Naval Postgraduate School, and optical instruments, the PSU radar, meteorological instruments, and aircraft measurements, in addition to the meteorological expertise and facilities of PSU researchers. Nature cooperated completely with the program objectives, as a polar front jet stream wandered in and out throughout the measurement period. All the instruments

Sample CLEAR II C_n^2 and Wind-Speed Profile Measured by Thermosonde. (The C_n^2 profile is obtained by arithmetically smoothing the 20 m resolution data using a Gaussian window with a sigma of 75 m).

painted a consistent picture of atmospheric conditions. The optical turbulence data exhibited an enhancement, via a thick layer of high turbulence, on the leading edge of the jet stream trough, but not on the trailing edge (see the figure). Indeed, the turbulence on the trailing edge is virtually indistinguishable from data in the absence of the jet or under low wind conditions. Thus, it appears that the presence of the jet stream does not necessarily imply degraded optical propagation or seeing conditions. The data are still being analyzed, but these preliminary results, as well as others, are very promising. This program also provided an ideal opportunity to test and evaluate the new design of the stellar scintillometer and to compare its C_n^2 results with other independent measurements. In particular, as a result of this program, the AFGL scintillometer has been found to provide reliable data on the isoplanatic angle. The data range of the scintillometer, from 2 to 18 km, does not provide sufficient range for integration of its output, C_n^2, to provide isoplanatic angle, and therefore models are used to allow integration beyond this range.

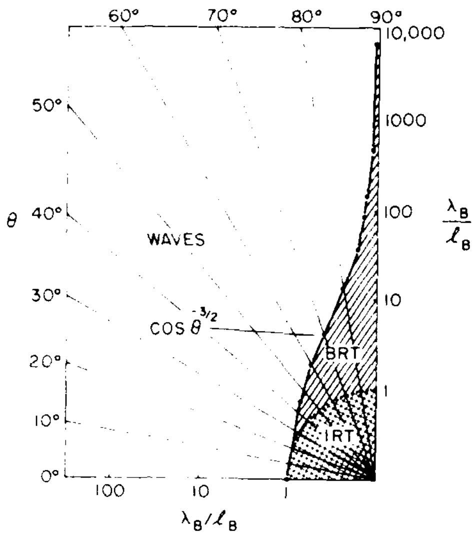


Measured Thermosonde C_n^2 Profile in Stratosphere (dashed curve) Superimposed on AFGL High Resolution Model (solid curve). (Note the characteristic layering of atmospheric optical turbulence in both the data and the model. The model uses only the pressure and temperature data measured concurrently with the C_n^2 profile.)

Analysis and Models: In addition to measurements, a major effort in optical turbulence research has been devoted to modeling, and its closely related application, forecasting. The AFGL modeling program relies heavily on thermosonde data to validate models, as well as on the analysis of thermosonde data. The model effort arranges itself in a natural hierarchy. There are the empirical averages, which are simple fits to the average of many thermosonde profiles. These do not involve any unspecified parameters and, in this sense, they are "no-parameter" models. However, they are different for different sites, season, and time of day. These AFGL model profiles are models for average turbulence conditions. Currently, AFGL models exist for White Sands Missile Range under a variety of meteorological conditions (CLEAR 1, 2, and 3, both day and night) and for AMOS (day and night). Such models are often used by laser engineers as simplified, "typical" altitude models of C_n^2 to estimate turbulence effects on a system or to specify design criteria (see the figure). Coefficients of the fits and the models were distributed to government sources and their system design contractors. The models also have been useful for contrasting and comparing turbulence for different locations and meteorological conditions. For example, the models illustrated the differences in turbulence intensity between New Mexico and Maui in the troposphere and elucidated the significant jet stream enhancement of C_n^2.

Another thrust of the modeling work has been to predict some of the detail and layering of the optical turbulence profile in the free atmosphere using standard radiosonde data. Such a model would be extremely useful, given the extensive network of meteorological stations throughout the world, and would allow synoptic, meteorological, and climatological studies. The VanZandt model has been investigated and compared to actual thermosonde data and has shown some success. This, however, is a statistical model which is computationally intensive. A similar model, developed at AFGL, also uses standard radiosonde data and is computationally simpler than the VanZandt model. The two models are comparable in their performance, and the refinement of the AFGL model is being pursued. Both of these models produce low-resolution turbulence profiles, because of the low-resolution nature of standard radiosonde data. Another effort uses the high-resolution meteorological data that is simultaneously gathered by the thermosonde. This has resulted in another AFGL model, currently applicable to stratospheric turbulence only, which has shown great promise in producing 100 meter resolution models of instantaneous optical turbulence profiles. This model is being pursued, especially its extension to the troposphere and the boundary layer.

This modeling of optical turbulence profiles is closely related to the analysis and modeling of optical propagation. This effort has concentrated on laser beam propagation, especially for ground-based laser systems currently of interest to the Air Force and the Strategic Defense Initiative Organization. The analysis and modeling of turbulence effects has been performed in terms of the various moments of the refractive index structure constant, C_n^2. These moments include coherence length, isoplanatic angle, scintillation variance, and Greenwood frequency. Overall characterization of a laser system performance has been studied at AFGL through the calculation of Strehl ratios, which are the ratios of peak intensity with, and without, a particular turbulence effect. These are the parameters used in applications to system and adaptive optics design, as well as to characterize overall conditions and laser-beam propagation effects. Using the AFGL database, optical physicists study the variation of these parameters and investigate the previously mentioned models for their usefulness in predicting these parameters. Further efforts have begun in applying linear predictive methods to forecasting short-term changes and fluctuations of the moments. Finally, these propagation analyses and models have been extended to incorporate the effects of thermal blooming. This effort has just begun and will result in an integrated optical propagation code, capable of modeling the effect of the atmosphere on the propagation of a laser beam from the ground up to space.



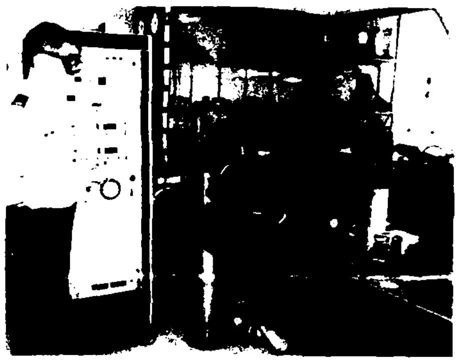
Buoyancy Range Turbulence (BRT). (This type of turbulence, expected in the stable atmosphere, was known to occur outside the circle enclosing IRT in this parameter plot. Inertial range turbulence (IRT) is the "cascading" homogeneous type most studied. AFGL discovered that BRT occupied the region shown, as a result of a comparison between the physics of turbulence and the physics of waves. BRT is a hybrid between waves and turbulence. This AFGL discovery should aid future investigators in understanding their data.)

AFGL has also conducted more fundamental research into the nature and origin of atmospheric turbulence. The internal buoyancy waves in the atmosphere, called gravity waves, are believed to be responsible for most of the optical turbulence above the planetary boundary layer. AFGL has therefore conducted an investigation of these waves in the hope of making use of the results in optical turbulence forecasting. For the first time the theory of gravity waves was used to explain why upper atmosphere wind shear amplitudes do not grow with altitude. The power spectrum of the shears is universal.

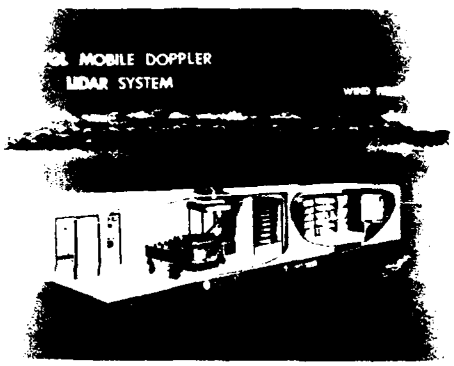
Climate, location, or time of year do not appear to have any noticeable effects on the spectrum, and this finding, based in part on our own experiments, is true in the atmosphere at all heights, and in the ocean as well. The spectrum represents a turbulent saturation effect (see the figure). Whenever there are departures from it, turbulence dumps out the excess energy and restores the universal form. In the present time period, further publications and data analysis have been completed and further convincing evidence for our hypothesis has been obtained. Our theory explained the observed dependence of spectral slope upon spectral amplitude and has generated much interest.

LIDAR TECHNOLOGY

Research in the remote sensing of optical and meteorological properties of the atmosphere using the techniques of laser radar, or lidar, is carried out as a part of the AFGL program in atmospheric optics. In lidar applications, observations are made of the light scattered (generally at 180°) from a laser beam as it propagates through the atmosphere. These observations are used to determine, as a function of range, the nature of the scattering elements present along the beam path at great distances from the transmitting source. Using this active approach to remote sensing, the AFGL program includes ground-based and balloonborne instrumentation to measure aerosol scattering and optical extinction, the concentration of minor species such as water vapor and carbon dioxide, and the magnitude and direction of atmospheric wind fields. Of principal interest in this program is the evolutionary transition of present ground-based and balloonborne technology to lidar systems based in space, which will ultimately provide global measurements of a full range of atmospheric parameters observed within the lower stratosphere and troposphere over seasonally significant time periods.



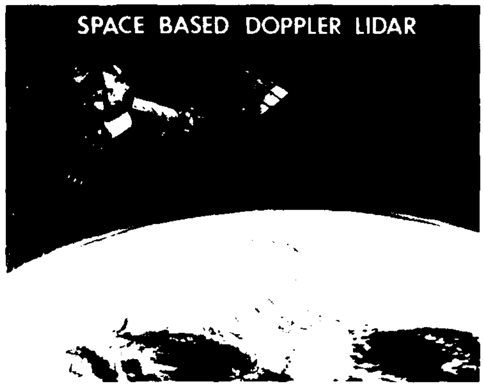
Laboratory Testing of New Type Injection-Locked CO_2 TEA Laser To Be Used in Upcoming High-Altitude Atmospheric Measurements.



AFGL Mobile Doppler Lidar System.

High-Altitude Lidar Measurements: Using both a laboratory lidar observatory (see the figure) and a trailer-mounted mobile system (see the figure), each similarly equipped. AFGL scientists have made range-resolved observations of atmospheric backscatter over a range of upper stratospheric and mesospheric altitudes. The laboratory measurements performed at the AFGL location have detected resonance scattering from meteoritic sodium at laser wavelengths in the visible and general Rayleigh scattering throughout the middle atmosphere region. The mobile lidar system has been placed in operation at both Wallops Island, Virginia, and Poker Flat Research Range, Alaska. It has successfully observed Rayleigh backscatter from very high altitudes, a region where the return signal is uncontaminated by scattering from aerosols and where it provides a direct measurement of the atmospheric density profile when calibrated by instrumental factors or by a reference density measurement. By using model derived relations, the temperature profile can be obtained from the observed densities. The lidar measurements at high northern latitudes were performed to obtain density data with high temporal resolution to establish general density profiles and the manner in which they change, in particular the nature of sharp density gradients which occur in this region and impact reentering spacecraft crossing polar latitudes.

Space-Based Lidar Measurements: The Laboratory is involved in the development of space-based lidar sensors on three technological fronts. Most direct has been the involvement with the Defense Meteorological Satellite Program (DMSP) Office in the development of an approach to the measurement of tropospheric winds from an operational spacecraft over a multiyear lifetime (see the figure). It is generally agreed in the meteorological community that the timely availability of winds data

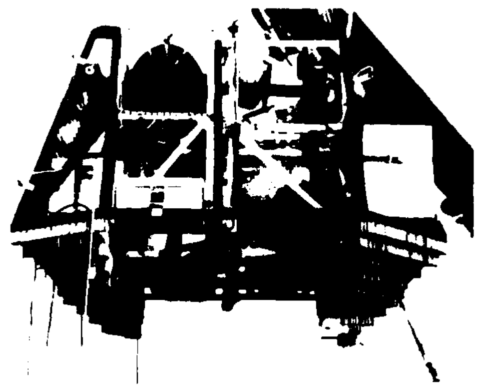


AFGL Space-Based Doppler Lidar.

on a global basis will have important consequences for improved forecasting. Wind speeds with meter-per-second accuracy and with good directional information appear to be obtainable from satellite systems as shown by results of extensive numerical simulations, although the required lidar technology is the most advanced within current planning cycles. In pursuit of these goals, the DMSP Office is following a multiphase approach to instrumentation of increasing complexity over the next several years. AFGL scientists are participating in these developments in an advisory capacity to DMSP and in management of an on-going lidar design study.

Closely related to these space system considerations is the development of a ground-based, trailer-mounted CO_2 coherent lidar for making wind-field measurements over a 30 km range in a hemispherical pattern centered at the lidar site. This highly stable, narrow linewidth laser system uses coherent techniques, including heterodyne detection, to achieve the sensitivity necessary to determine wind speed from the Doppler-shifted backscatter returns produced by aerosols co-moving with the atmospheric wind field. A laser currently under development for this specific task has output power in the 1 to 5 joule per pulse range at 50 pulses per second. The laser design is based on electron beam excitation of CO_2 at near atmospheric pressure (TEA laser). In addition to the research effort required to bring this laser system to operational status, sophisticated signal processing and data display and analysis techniques are in the course of parallel development. Although the ground-based system hardware and its resource requirements are inappropriate for use in space, the measurement techniques and the signal-processing software developments have close analogy to presently planned wind-sensing systems for use in space, and these current research efforts will contribute importantly to future designs for space-based systems. The wind-measuring capability of this CO_2 mobile system has direct application to meteorological needs other than systems developed for use in space since it has the capability to sense wind shear and other severe weather phenomena in the vicinity of airfields and other sensitive areas.

A third area of lidar development with ultimate application to space-based technology is in balloonborne systems which provide an intermediate step toward space in the manner in which they simulate flight under severe environmental conditions at very high altitude and in providing an observational vantage point above, and essentially outside, the sensible atmosphere. A system flown in the past (see the figure) contains a doubled and tripled Nd:YAG laser transmitter. Currently being added is a state-of-the-art CO_2 laser system with sufficient stability to allow coherent operation and to provide aerosol scattering data in a wholly different spectral region in the infrared. A balloonborne system for Raman scattering measurements of water vapor and carbon dioxide presently in design will make observations during the ascent and descent portions of the balloon flight profile as well as from float altitude. In simulating the observational viewpoint of a satellite sensor, the balloonborne systems provide baseline data on backscatter signal levels and related system parameters which can then be scaled to other altitudes, system geometries, and sensitivity levels to guide the design and the anticipated performance of the space-based lidar system.



AFGL Balloonborne Lidar.

INFRARED CELESTIAL BACKGROUND

The performance of an upward-looking infrared surveillance sensor is limited by the general nature and detailed character of the naturally occurring background against which the system must operate. The Optical Physics Division conducts spaceborne experiments to measure this background, and is responsible for reducing and analyzing these and other experimental data in order to create a basis for performing realistic system trade-off analysis.

During the last year the Celestial Backgrounds group constructed and successfully tested an imaging spectrometer for use at ground-based observatories. The heart of this instrument is a 58×62 element Si:As mosaic direct readout detector array. This instrument is capable of obtaining either high-resolution images in selectable spectral bands in the 8-14 μm region or simultaneous 8-14 μm spectra over a spatial region several arc minutes in extent.

The Visual Photometric Experiment, a Get Away Special experiment for the shuttle, was designed, constructed, and tested during 1986. This experiment will obtain large-scale B, V, R and H alpha-measurements of the diffuse galactic and zodiacal background. These data will constrain the parameters in the long wavelength infrared phenomenology models, particularly those for the zodiacal background.

Work on the Diffuse Infrared Galactic Background Experiment began in 1986. The objective of this experiment is to obtain 5-18 μm spectra at 2 percent resolution for several regions along the galactic plane, the galactic center, several H II regions and reflection nebulae and, hopefully, of the brightest infrared "cirrus." The infrared cirrus is whispy long wavelength infrared emission related to interstellar dust. It has been speculated that the unusually strong long wavelength infrared flux from this background, as well as from reflection nebulae and H II regions, is due to band emission from either polycyclic aromatic hydrocarbons or partially hydrogenated amorphous carbon. High quality spectra are needed to provide a basis for identifying the emitting species and to analyze the astrophysical conditions under which differing compounds are formed. Because of the extended nature of this emission it can only be studied from a space platform.

Physical and phenomenological modeling of the various celestial background components continued in 1986 with some emphasis placed on high spatial resolution. A major new effort began to superresolve long wavelength infrared celestial survey data, initially that from the Infrared Astronomy Satellite. This requires advancing the state-of-the-art in image enhancement as survey data are quite different from the rectilinear images taken with a symmetric beam profile that the current standard super-resolution algorithms demand. Several procedures are being developed; to date a resolution improvement by about a factor of 50 has been obtained on special survey observations.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

ALEJANDRO, S.B., and FITZGERALD, D.R.
Air Force Geophysics Laboratory's (AFGL) Mobile CO2 Doppler Lidar
Digest of Optical Remote Sensing of the Atmosphere Conf. (15-18 January 1985)

ANDERSON, G.P., and HALL, L.A.
Stratospheric Determination of O_2 Cross Sections and Photodissociation Rate Coefficients: 191-215 nm
J. Geophys. Res. 91 (1986)

ANDERSON, G.P. (AFGL); MILLIER, F.C. (Laboratoire de Physique Stellaire et Planetaire, Verriere-le-Buisson, France);

AIKIN, A.C. (NASA/GSFC, Greenbelt, MD); GILLE, J.C. (NCAR, Boulder, CO)
Intercomparison of Mesospheric Ozone Measurements Using the LRIR and UVMCS Satellite Instruments
Ann. Geophys. 3 (1985)

BEDO, D.E. and SWIRBALUS, R.A.
Atmospheric Backscatter Observations from a Balloonborne Lidar
Proc. 13th Internat. Laser Radar Conf. (11-15 August 1986)

BIONDI, M.A. (Univ. of Pittsburgh, Pittsburgh, PA); and SIPLER, D.P. (AFGL)
Horizontal and Vertical Winds and Temperatures in the Equatorial Thermosphere: Measurements from Natal, Brazil, During August-September 1982: Studies of Equatorial 630.0 nm Airglow Enhancements Produced by a Chemical Release in the F-Region
Planetary and Space Sci. 32 (1984)

BIONDI, M.A. (Univ. of Pittsburgh, Pittsburgh, PA); SIPLER, D.P. (AFGL); and WEINSCHENKER, M. (Univ. of Pittsburgh, Pittsburgh, PA)
Multiple Aperture Exit Plate for Field-Widening a Fabry-Perot Interferometer
J. Appl. Opt. 24 (1985)

DEWAN, E.M.
On the Nature of Atmospheric Waves and Turbulence
J. Radio Sci. 20 (Nov-Dec 1985)
Atmospheric Waves and the Nature of Buoyancy Turbulence in the Context of the Waves vs 2-D Turbulence Debate
MAP Handbook 20 (Aug 1986)
A Proposed Experimental Test to Distinguish Between Waves from 2-D Turbulence
MAP Handbook 20 (August 1986)

DEWAN, E.M., and GOOD, R.E.
Saturation and the "Universal" Spectrum for Vertical Profiles of Horizontal Scaler Winds in the Atmosphere
J. Geophys. Res. 91 (20 February 1986)

EATON, F.D., GARVEY, D.M. (Atmospheric Sci. Lab., White Sands Missile Range, NM); DEWAN, E., and BELAND, R. (AFGL)
Transverse Coherence Length (r_o) Observations
SPIE Vol. 551 (1985)

ESPLIN, M.P. (Stewart Radiance Lab., Bedford, MA); and ROTHMAN, L.S. (AFGL)
Spectral Measurements of High Temperature Isotopic Carbon Dioxide in the 4.5 μm and 2.8 μm Regions
J. Molecular Spectroscopy 116 (1986)

GAMACHE, R.R. (Univ. of Lowell, Lowell, MA); and ROTHMAN, L.S. (AFGL)
Theoretical N_2-Broadened Halfwidths of $^{16}O_3$
Appl. Opt. 24 (1 June 1985)

GAMACHE, R.R. (Univ. of Lowell, Lowell, MA); DAVIES, R.W. (GTE, Waltham, MA); and ROTHMAN, L.S. (AFGL)
Theoretical N_2, O_2, and Air-broadened Halfwidths of Ozone Calculated by Quantum Fourier Theory with Realistic Collision Dynamics in *Atmospheric Ozone*,
ed. C. Zerefors and A. Ghazi, D. Reidel Pub. (1985)

GARDNER, C.S. (Univ. of Illinois, Urbana, IL); PHILBRICK, C.R. (AFGL); VOELZ, D.G. (Univ. of Illinois, Urbana, IL); and SIPLER, D. (AFGL)
Simultaneous Lidar Measurements of the Sodium Layer Structure at the Air Force Geophysics Laboratory and the University of Illinois
J. Geophys. Res. 91 (November 1986)

LITTLE, S.J., and PRICE, S.D.
Infrared Mapping of the Galactic Plane. IV. The Galactic Center
Astron. J. 90 (September 1985)

LITTLE-MARENIN, I.R.
Carbon Stars with Silicate Dust in Their Circumstellar Shells
Astrophys. J. Lett. 307 (1 August 1986)

LITTLE-MARENIN, I.R., and PRICE, S.D.
The Shapes of the Circumstellar "Silicate" Features
Proc. Summer School of Interstellar Processes (2-7 July 1986)

MURCRAY, D.G., MURCRAY, F.H., MURCRAY, F.J. (Univ. of Denver, Denver, CO); and VANASSE, G.A. (AFGL)
Measurements of Atmospheric Emission at High Spectral Resolution
J. of the Meteor. Soc. of Japan 63 (28 April 1985)

MURDOCK, T.L., and PRICE, S.D.
Infrared Measurements of Zodiacal Light
Astron. J. 90 (February 1985)

MURPHY, E.A., DEWAN, E.M., and SHELDON, S.M.
Daytime Comparisons of C_n Models to Measurements in a Desert Location
SPIE Adaptive Optics 551 (1985)

PHILBRICK, C.R. (AFGL); BUFTON, J.L. (NASA/GFSC, Wallops Island, VA); and GARDNER, C.S. (Univ. of Illinois, Urbana, IL)
A Solid State Tunable Laser for Resonance Measurements of Atmospheric Sodium
Springer Series in Optical Sciences 51 (1986)

PHILBRICK, C.R., SIPLER, D.P., BALSLEY, B.B., ULWICK, J.C.
The STATE Experiment - Mesospheric Dynamics
Adv. Space Res. 4 (1984)

PHILBRICK, C.R. (AFGL); BARNETT, J.J. (Oxford Univ., Oxford, UK); GERNDT, R., OFFERMANN, D. (Univ. of Wuppertal, Wuppertal, FRG); PENDLETON, W.R., JR. (Utah St. Univ., Logan, UT); SCHLYTER, P. (Univ. of Stockholm, Stockholm, Sweden); SCHMIDLIN, F.J. (NASA, Wallops Island, VA); and WITT, G. (Univ. of Stockholm, Stockholm, Sweden)
Temperature Measurements During the Camp Program
Adv. Space Res. 4 (1984)

PHILBRICK, C.R. (AFGL); SCHMIDLIN, F.J. (NASA Goddard Space Flight Ctr., Wallops Island, VA); GROSSMANN, K.U., LANGE, G., OFFERMANN, D. (Univ. of Wuppertal, Wuppertal, FRG); BAKER, K.D. (Utah St. Univ., Logan, UT); KRANKOWSKY, D. (Max-Planck Institut für Kernphysik, Heidelberg, FRG); and VONZAHN, U. (Univ. of Bonn, Bonn, FRG)
Density and Temperature Structure Over Northern Europe
J. Atmos. and Terr. Phys. 47 (1985)

PRICE, S.D.
Interplanetary Dust
Proc. ESA Wkshp. on Space-Borne Sub-Millimeter Astronomy Mission (4-7 June 1986)
Structure of the Extended Emission in the Infrared Celestial Background
SPIE Symp. ID #685-25 (30 September 1986)

ROTHMAN, L.S.
Infrared Energy Levels and Intensities of Carbon Dioxide - III
J. Appl. Opt. 25 (1 June 1986)

ROTHMAN, L.S. (AFGL); and WATTSON, R.B. (Visidyne, Inc., Burlington, MA)
Determination of Vibrational Energy Levels and Parallel Band Intensities of $^{12}C^{16}O_2$ by Direct Numerical Diagonalization
J. Molecular Spectroscopy 119 (September 1986)

STAIR, A.T., SHARMA, R.D., NADILE, R.M. (AFGL); BAKER, D.J. (Utah St. Univ., Logan, UT); and GRIEDER, W.F. (Boston Coll., Newton, MA)
Observations of Limb Radiance with Cryogenic Spectral Infrared Rocket Experiment
J. Geophys. Res. 90 (1 October 1985)

TRAKHOVSKY, E.
Ozone Amount Determined by Transmittance Measurements in the Solar-Blind Spectral Region
J. Appl. Opt. 24 (1985)

TRAKHOVSKY, E., and SHETTLE, E.P.
Improved Inversion Procedures for the Retrieval of Aerosol Size Distributions Using Aureole Measurements
J. Optical Soc. of Am. 2 (November 1985)

WARREN, S.G. (Univ. of Washington, Seattle, WA); and SHETTLE, E.P. (AFGL)
Optical Constants of Ice in the Infrared Atmospheric Windows
Proc. Sixth Conf. on Atmospheric Radiation (13-16 May 1986)

WHITE, K.O., GARVEY, D.M. (U.S. Army Eradcom, White Sands Missile Range, NM); and GOOD, R.E. (AFGL)
Optical Propagation Characterization at WSMR HIDL Test Site
SPIE Adaptive Optics 551 (1985)

PRESENTATIONS AT MEETINGS JANUARY, 1985 - DECEMBER, 1986

BATTLES, F.P. (Massachusetts Maritime Academy, Buzzards Bay, MA); MURPHY, E.A. (AFGL); and NOONAN, J.P. (Bedford Research, Bedford, MA)
The Contributions of Atmospheric Density to the Drop-Off Rate of C_n^2
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

BEDO, D.E., and SWIRBALUS, R.A.
Backscatter Measurements from a Balloon-borne Lidar
AGU Mtg., Baltimore, MD (27-31 May 1985)

BELAND, R.R., and BROWN, J.H.
A Deterministic Temperature Model for Stratospheric Optical Turbulence
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

BROWN, J.H., and BELAND, R.R.
A Site Comparison of Optical Turbulence in the Lower Stratosphere at Night Using Thermosonde Data
XXVI COSPAR Mtg., Toulouse, France (30 June - 12 July 1986)

BROWN, J.H., BELAND, R.R. (AFGL); EATON, F.D., and PETERSON, W.A. (ASL, White Sands Missile Range, NM)
Isoplanatic Angle (θ_o) Observations
SPIE Mtg., Arlington, VA (8-12 April 1985)

CLOUGH, S.A., KNEIZYS, F.X., ANDERSON, G.P., and SHETTLE, E.P.
AFGL Radiance/Transmittance Models: FASCODE and LOWTRAN
IAGA/IAMAP Joint Assbly., Prague, Czechoslovakia (12 August 1985)

CLOUGH, S.A., KNEIZYS, F.X., SHETTLE, E.P., and ANDERSON, G.P.
Atmospheric Radiance and Transmittance: FASCODE2
Sixth Conf. on Atmospheric Resolution, Williamsburg, VA (May 1986)

DAVIES, R.W. (GTE Lab., Waltham, MA); CLOUGH, S.A., and KNEIZYS, F.X. (AFGL)
Line Shapes for Atmospheric Molecules: Calculations for Water Vapor
Ninth Colloquium on High Resolution Spectroscopy, Riccione, Italy (16-20 September 1985)

DEWAN, E.M.
Waves and Turbulence: The Physical Difference
Waves and Turbulence Workshop, LaJolla, CA (2 December 1986)

DEWAN, E.M., and GOOD, R.E.
Power Spectral Densit[illegible] (PSD's) of Stratospheric Wind[illegible] d Implications for Gravity Wave Experiments and Theory
AGU Meeting, Baltimore, MD (19-30 May 1986)
Explanation of the Universal Spectrum of Gravity Waves
Waves and Turbulence Workshop, LaJolla, CA (2 December 1986)

DEWAN, E.M. (AFGL); GROSSBARD, N. (Boston Coll., Newton, MA); GOOD, R.E., and QUESADA, A. (AFGL)
Power Spectral Densities of Zonal and Meridional Winds in the Stratosphere
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

ESPLIN, M.P. (Stewart Radiance Lab., Bedford, MA); and MYCROFT, J.P. (AFGL)
Line Position Measurements of C O and C O O at Elevated Temperatures in the 2.8 μm Region
40th Symp. on Molecular Spectroscopy, Columbus, OH (17-21 June 1985)
Line Positions of $\Delta\nu$ = 1 Bands of C O O
Symp. on Molecular Spectroscopy, Columbus, OH (16-20 June 1986)

FITZGERALD, D.R.
Aircraft and Rocket Triggered Lightning Experiments of the 1960's
AGU Mtg., San Francisco, CA (9-13 December 1985)

GAMACHE, R.R. (Univ. of Lowell, Lowell, MA); and ROTHMAN, L.S. (AFGL)
Temperature Dependence of N2 Broadened Halfwidths of H_2O
41st Symp. of Molecular Spectroscopy, Columbus, OH (16-20 June 1986)

GARDNER, C.S. (Univ. of Illinois, Urbana, IL); PHILBRICK, C.R. (AFGL);

VOELZ, D.G. (Univ. of Illinois, Urbana, IL); and SIPLER, D. (AFGL)
Simultaneous LIDAR Measurements of the Sodium Layer Structure at the Air Force Geophysics Laboratory and the University of Illinois
13th Internat. Laser Radar Conf., Toronto, Canada (11-15 August 1986)

GOOD, R.E. (AFGL); GARVEY, D.M., PETERSON, W.A. (ASL, White Sands Missile Range, NM); and BROWN, J.H. (AFGL)
Impact of Turbulence on Laser Propagation from WSMR HIDL Site
SPIE Mtg., Arlington, VA (April 1985)

KOENIG, G.G.
Extinction and Scattering Properties of Falling Snow
Snow Symp. VI., Hanover, NH (12-14 August 1986)

KOENIG, G.G. (AFGL); LIOU, K.N., and GRIFFIN, M. (Univ. of Utah, Logan, UT)
Investigation of the Climatic Effects of Clouds Using 3DNEPH and Earth Radiation Budget Data
IAMAP IAPSO Joint Assbly., Honolulu, HI (4-10 August 1985)

LEVAN, P.D., and PRICE, S.D.
IRAS Line Fluxes in the Starburst Galaxy M82
167th Mtg. of the Am. Astron. Soc., Houston, TX (6-9 January 1986)

LEVAN, P.D., MURDOCK, T.L., TANDY, P.C. and LITTLE, S.J.
The AFGL Infrared Mosaic Spectrometer
166th Mtg. of Am. Astron. Soc., Charlottesville, VA (3-7 June 1985)

MURPHY, E.A., and SHELDON, S.
C_n^2 Modeling Above the Convective Boundary Layer
SPIE Mtg., Arlington, VA (April 1985)

OFFERMAN, D., KUCHLER, R., LANGE, G. (Univ. of Wuppertal, FRG); PHILBRICK, C.R. (AFGL); and

SCHMIDLIN, F.J. (NASA Goddard Space Flight Ctr., Wallops Island, VA)
Dynamical Features in the Middle Atmosphere at High Latitudes During a Minor Stratospheric Warming
XXVI COSPAR Mtg., Toulouse, France (30 June-12 July 1986)

PRICE, S.D.
Interplanetary Dust
European Space Agency Wkshp., Segovia, Spain (4-7 June 1986)

ROTHMAN, L.S.
HITRAN, The Molecular Absorption Database, XXVI COSPAR Mtg.,
Toulouse, France (30 June - 12 July 1986)

ROTHMAN, L.S.
HITRAN, the Molecular Absorption Database
Sixth Conf. on Atmos. Radiation, Williamsburg, VA (May 1986)

ROTHMAN, L.S. (AFGL); and GAMACHE, R.R. (Univ. of Lowell, Lowell, MA)
Temperature Dependence of N_2-Broadened Halfwidths of Ozone
40th Symp. of Molecular Spectroscopy, Columbus, OH (17-21 June 1985)

ROTHMAN, L.S. (AFGL); and WATTSON, R.B. (Visidyne, Inc., Burlington, MA)
Energy Levels and Band Strengths of Carbon Dioxide Calculated by Direct Numerical Diagonalization
40th Symp. on Molecular Spectroscopy, Columbus, OH (17-21 June 1985)

ROTHMAN, L.S. (AFGL); WATTSON, R.B. (Visidyne, Inc., Burlington, MA); and GAMACHE, R.R. (Univ. of Lowell, Lowell, MA)
The New Version of the HITRAN Database: Example of Carbon Dioxide Line Parameters
41st Symp. of Molecular Spectroscopy, Columbus, OH (16-20 June 1986)

ROTHMAN, L.S., VANASSE, G.A. (AFGL); MURCRAY, F.H., MURCRAY, F.J., MURCRAY, D.G. (Univ. of Denver, Denver, CO)
Balloon-borne Atmospheric Infrared Emission Spectra Obtained with the SCRIBE Interferometer
40th Symp. on Molecular Spectroscopy Columbus, OH (17-21 June 1985)

ROTHMAN, L.S., VANASSE, G.A. (AFGL); MURCRAY, D.G., MURCRAY, F.H., MURCRAY, F.J., and GOLDMAN, A. (Univ. of Denver, Denver, CO)
Atmospheric Emission Spectra from the Stratospheric Cryogenic Interferometer Balloon Experiment
Ninth Colloquium on High Resolution Spectroscopy, Riccione, Italy (16-20 September 1985)

SHETTLE, E.P.
Backscattering by Atmospheric Aerosols
IAMAP/IAPSO Joint Assbly., Honolulu, HI (5-16 August 1985)

TRAKHOVSKY, E.
Solar Blind UV Forward Scatterometer
An. Mtg. of the Optical Soc. of Am., Washington, DC (14-18 October 1985)

TRAKHOVSKY, E., and SHETTLE, E.P.
Inversion Procedure for the Retrieval of Aerosol Size Distributions
An. Mtg. of the Optical Soc. of Am., Washington, DC (14-18 October 1985)
Aerosol Size Distribution from the Inversion of Forward Scattering Measurements
Sixth Conf. on Atmos. Radiation, Williamsburg, VA (13-16 May 1986)

VANASSE, G.A. (AFGL); MURCRAY, D.G., MURCRAY, F.H., and MURCRAY, F.J. (Univ. of Denver, Denver, CO)
Stratospheric Cryogenic Interferometer Balloon Experiment (SCRIBE) Interferometer Atmospheric Emission Spectra
Internat. Conf. on Fourier Spectroscopy, Ottawa, Canada (24-28 June 1985); IAGA Scientific Assbly., Prague, Czechoslovakia (5-17 August 1985)

VOLZ, F.
IR Absorption by Submicron Aerosols
Sixth Conf. on Atmos. Radiation, Williamsburg, VA (13-16 May 1986)

WATKINS, B.J. (Univ. of Alaska, Fairbanks, AK); PHILBRICK, C.R. (AFGL); and BALSLEY, B.B. (NOAA Aeronomy Lab., Boulder, CO)
Turbulence Energy Dissipation Rates in the Middle Atmosphere
GLOBMET Symp., Dushanbe, USSR (19-24 August 1985)

WATTSON, R.B. (Visidyne, Inc., Burlington, MA); and ROTHMAN, L.S. (AFGL)
Sensitivity of Band Intensities of Carbon Dioxide to Experimental Data in Direct Numerical Diagonalization Calculations
41st Symp. of Molecular Spectroscopy, Columbus, OH (16-20 June 1986)

TECHNICAL REPORTS JANUARY, 1985 - DECEMBER, 1986

ANDERSON, G.P., CLOUGH, S.A., KNEIZYS, F.X., CHETWYND, J.H., and SHETTLE, E.P.
AFGL Constituent Profiles (0-120km) AFGL-TR-86-0110 (15 May 1986), ADA175173

DEWAN, E.M.
A Review of Maximum Entropy Spectral Analysis and Applications to Fourier Spectroscopy
AFGL-TR-85-0091 (3 April 1985), ADA164698

ESPLIN, M. P. (Stewart Radiance Lab., Bedford, MA); SAKAI, H. (Univ. of Mass., Amherst, MA); ROTHMAN, L.S., and VANASSE, G. A. (AFGL); BAROWY, W. M., and HUPPI, R. I. (Stewart Radiance Lab., Bedford, MA)
Carbon Dioxide Line Position in the 2.8 and 4.3 Micron Regions at 800 Kelvin
AFGL-TR-86-0046 (February 1986) ADA 173808

CONTRACTOR TECHNICAL REPORTS JANUARY, 1985 - DECEMBER, 1986

BERRY, R.C., and MADRID, C.R. (Rockwell Internat., Anaheim, CA)
Survey Probe Infrared Celestial Experiment (SPICE)
AFGL-TR-85-0087 (January 1985), ADA164701

BURCH, D.E. (Ford Aerospace and Communications Corp., Newport Beach, CA)
Absorption by H_2O in Narrow Windows Between 3000 and 4200 cm^{-1}
AFGL-TR-85-0036 (March 1985), ADA166648

DAVIES, R.W., and FAHEY, S.F. (GTE Lab., Inc., Waltham, MA)
Calculation of H_2O Far Wing Absorption Within the Single-Perturber Approximation
AFGL-TR-85-0033 (February 1985), ADA160405

GAMACHE, R.R. (Univ. of Lowell, Lowell, MA)
Microwave and Infrared Absorption Properties of Atmospheric Species with Special Emphasis on Line Widths and Shifts
AFGL-TR-85-0168 (July 1985), ADA162154

HOFMANN, D.J., and ROSEN, J.M. (Univ. of Wyoming, Laramie, WY)
Study of Large Aerosol Particles
AFGL-TR-85-0096 (3 May 1985), ADA160379

ISAACS, R.G., WANG, W.-C., WORSHAM, R.D., and GOLDENBERG, S. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Multiple Scattering Treatment for Use in the LOWTRAN and FASCODE Models
AFGL-TR-86-0073 (7 April 1986), ADA 173990

LIN, C.-C., and CHUNG, S. (Univ. of Wisconsin, Madison, WI)
Molecular Reaction Rates
AFGL-TR-85-0262 (28 October 1985), ADA166518

MURCRAY, F.H., MURCRAY, F.J., MURCRAY, D.G., and GOLDMAN, A. (Univ. of Denver, Denver, CO)
Measurement of Atmospheric Emission Spectra at High Altitudes
AFGL-TR-86-0061 (22 Nov 1985), ADA170143

PATTERSON, E.M. (Georgia Inst. of Tech., Atlanta, GA)
Optical Absorption Characteristics of Aerosols
AFGL-TR-85-0204 (11 September 1985), ADA165216

RYGNAR, E., and BARTLO, J.A. (Univ. of Michigan, Ann Arbor, MI)
Dependence of C_n^2, (C_T^2) in the Atmospheric Boundary Layer on Conventional Meteorological Variables
AFGL-TR-86-0013 (January 1986), ADA169478

SAKAI, H. (Univ. of Massachusetts, Amherst, MA)
Processing of SCRIBE Data
AFGL-TR-85-0279 (September 1985), ADA165226

SHEPHERD, O., AURILIO, G., BUCKMAN, R.D., HURD, A.H., and SHEEHAN, W.H. (Visidyne, Inc., Burlington, MA)
Project ABLE: Atmospheric Balloonborne Lidar Experiment
AFGL-TR-85-0064 (25 March 1985), ADA160372

Launch of SPIRIT I Cryogenic Infrared Auroral Earth Limb Sensor from the Poker Flat Rocket Range in Alaska. (The trajectory of the first stage of the two-stage Talos Castor rocket system can be seen in the photograph.)

VI INFRARED TECHNOLOGY DIVISION

The Infrared Technology Division performs research on the infrared emissions of the earth's atmosphere to determine the spectral and spatial nature of this radiation, to identify the physical and chemical processes producing the emission, and to understand its variability with geophysical conditions. This information is required to assess the ability of proposed and conceptual Air Force infrared surveillance systems to detect and track a target.

Ambient atmospheric infrared radiance varies markedly with altitude (with and without solar illumination), with latitude, and with solar and geomagnetic activity. Very significantly enhanced infrared emissions occur in polar regions during periods of auroral activity at altitudes in excess of approximately 90 km. They are produced by the distinct processes initiated by the collision of energetic particles with the atmosphere. In addition, nuclear detonations produce copious amounts of infrared radiation that is intense, persistent, and highly structured.

Research on atmospheric infrared processes is pursued by the Infrared Technology Division in laboratory studies and in field measurements using advanced cryogenic infrared sensors on measurement platforms on the ground and on balloons, aircraft, sounding rockets, and the shuttle.

The results from the various experimental programs are interpreted and quantified in terms of specific physical or chemical processes which are included in models of infrared atmospheric airglow and auroral emissions. The infrared airglow and auroral models provide designers of infrared systems an ability to assess proposed designs for the detection and tracking of targets as projected against a variety of backgrounds.

In addition, an NKC-135 aircraft is equipped with an array of infrared spectral and imaging sensors to observe specific aircraft and other target signatures. The target signatures are systematically recorded in a variety of operational conditions and against different backgrounds. The cryogenic infrared instruments on the NKC-135 aircraft have been designed and developed by the Infrared Technology Division to be insensitive to operation in a high vibration environment and are based on advanced optical design concepts and detector technology.

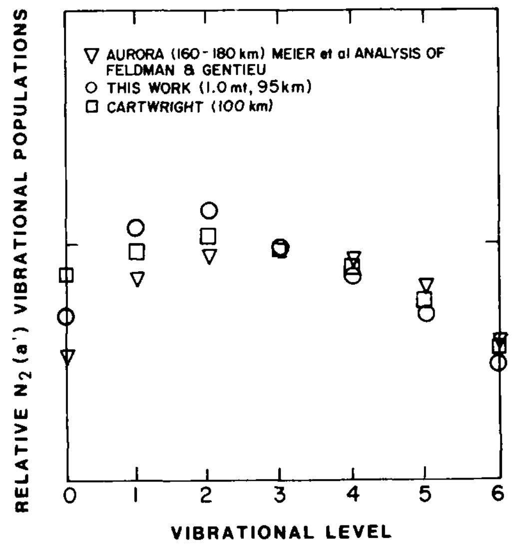
LABORATORY STUDIES

Specific atmospheric processes producing infrared emission are studied in a series of different laboratory facilities using a variety of excitation mechanisms. The Laboratory studies offer the unique opportunity to investigate specific microscopic chemi-dynamic processes under controlled conditions. Specific parameters, collision cross sections, rate coefficients, detailed vibrational populations, collisional deactivation rates, and radiative lifetimes are measured for the specific electronic and vibrational states of a given species. These parameters characterize the significance of a given process as a source of atmospheric infrared radiation in the ambient atmosphere or in aurorally or nuclear disturbed atmospheres. Results from the laboratory program are utilized to interpret airglow and auroral field measurements, which validate and confirm the significance of a given process. This approach has contributed significantly to the understanding of infrared atmospheric mechanisms. The laboratory experimental techniques include electron beam excitation, microwave discharge afterglow chemiluminescence, flowing afterglow studies with laser-induced fluorescence, Fourier transform mass spectrometry, and laser-induced plasma radiation.

LABCEDE: In the LABCEDE (Laboratory Cryogenic Electron Dependent Emissions) program, the production of infrared radiation by the interaction of electrons with the constituents of the atmosphere is investigated. Two particularly important sources of bright, structured infrared background radiation in the upper atmosphere are the aurora and nuclear explosions. In both cases, collisions between electrons and the constituent molecules of the atmosphere result in the emission of infrared radiation. The atomic and molecular species which radiate in the infrared are either excited directly by electron impact or are produced by chemical reactions which are initiated by electron scattering. The measurement of the relative efficiencies of excitation of those molecular states, which are important sources of infrared radiation in the upper atmosphere, and the characterization of processes which control the brightness of those infrared emissions are primary objectives of the LABCEDE program.

The cryogenic LABCEDE facility has been developed to make experimental measurements of infrared emissions from electron irradiated gases. The internal walls of the system are operated at 80° K to reduce the thermal infrare ba - ground and to increase the detection sensitivity of the system by four orders of magnitude at 10 μs. As a result of the low thermal background and the large volume of the observation region, weak infrared emissions can be detected from samples at pressures corresponding to altitudes of 60 to 110 km. (This altitude range includes the region where x-rays from high-altitude nuclear explosions are absorbed.) Gas samples can be irradiated by up to 20 mA currents of 2-6 keV electrons. The maximum available electron flux exceeds auroral fluxes by several orders of magnitude and is comparable to the nuclear case. A magnetic field can be applied to control independently the density of higher energy primary electrons and the low-energy secondary electrons produced by ionization. The gas pressure and flow rate in the LABCEDE chamber can be varied independently to investigate the effects of electron impact on species created by the electron beam. Condensible species such as CO_2 can be made to flow through the LABCEDE chamber when the cryoshroud is cooled down.

Another major capability of the facility is the irradiation of electron-excited gases by light beams originating outside the chamber, including light from a solar ultraviolet simulator (to simulate the daylit aurora), and by laser beams, to precisely perturb or probe populations of specific states of irradiated samples. Fluorescence excited by electron irradiation can be observed from the ultraviolet to the long wavelength infrared, using grating spectrometers in the ultraviolet/visible wavelength region, a cryogenic circular variable filter, which covers important bands in the 2-15 μ region, and room temperature and cryogenic interferometers to make observations in the 2-7 μ and 2-20 μ regions, respectively. In addition, a spatially scanning 3914 Å photometer is used to monitor the spatial distribution of energy deposited by energetic electrons in the beam and to normalize the intensity of fluorescence observed to the production of ion pairs in the beam.

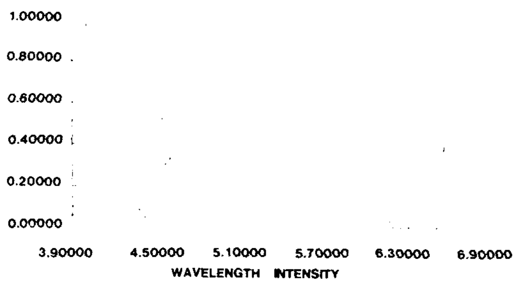


Comparison of LABCEDE, Auroral Observation, and Theoretical Calculations of the Uncollisionally Relative Populations of N_2(a) Vibrational Levels in Irradiated N_2 at Low Pressure.

A number of investigations of the excitation and collisional and radiative de-excitation of important infrared radiating states in the aurora and nuclear-disturbed atmosphere have been performed using the LABCEDE facility. Prominent in the electron-disturbed atmosphere are the Lyman-Birge-Hopfield bands in the ultraviolet spectral region and the 3-8 μ McFarlane bands which arise from the àπg state of N_2. The electron-impact excitation and quenching of the àπg state have been measured. Under low-pressure (equivalent to high altitude), collisionless conditions, the observed distribution of population over vibrational levels of the N_2(a) state is consistent with the Franck-Condon factors for electron impact excitation and radiative relaxation (see the figure). At higher pressures (equivalent to lower altitudes) where collisions are important, the dynamics of the relaxation of the vibrational levels of the N_2(a) state are much more complicated. The vibrational levels are electronically quenched at a moderate rate independent of the level of vibrational excitation. The higher levels, v = 4-6, collisionally relax by single quantum transitions at a very fast rate. However, the lower levels are collisionally coupled to the nearby à state.

To interpret the quenching data for these vibrational levels, the effects of the collisional coupling of a and à states were modeled. Fast, effective vibrational relaxation rates were determined for these lower levels. These results are chemically interesting because electronic quenching rates usually are faster than vibrational relaxation rates. These excitation and quenching data are important for predicting the altitude dependence of Lyman-Birge-Hopfield band emissions in the aurora and airglow, which is currently not understood in detail. In addition, these data are needed to predict the brightness of McFarlane band emission in the 3-4 μ and 7-9 μ radiance windows.

Previously, the N_2 pressure-dependence of the relative populations of the vibrational levels of the N_2 ($B^3\pi g$) state were measured. This investigation was undertaken because transitions from the N_2 ($B^3\pi g$) state (to the N_2 ($A^3\Sigma\mu$) state) are responsible for the bright First-Positive bands observed in the electron-disturbed upper atmosphere. The relative populations of B-state vibrational levels v = 3-9 were found to be invariant with pressure (altitude). The pressure dependence of the low (v = 0-2) and high (v = 10-12) vibrational levels of the B-state has been characterized. One question left unanswered by the earlier measurements was the effect of collisions with O_2 on the relative populations of the B-state vibrational levels. Recent measurements demonstrate that, as was the case with N_2, collisions with oxygen do not significantly change the relative populations of the mid (v = 3-9) vibrational levels of the B state.



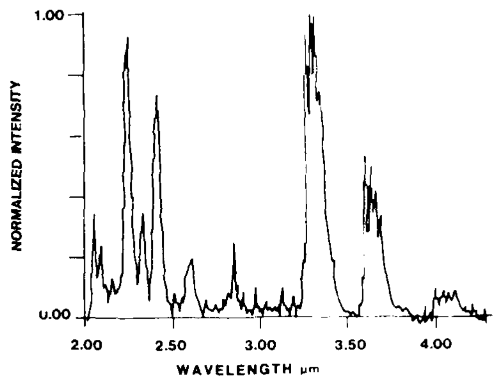
Atomic Oxygen Medium Wavelength Infrared Emissions in Electron-Irradiated O_2 Observed in LABCEDE under Collisionless Conditions.

Highly excited atomic oxygen is an important infrared radiator in high-altitude nuclear fireballs (see the figure). The brightness of emissions from, and the distribution of, the population over highly excited energy levels of the oxygen atom produced by electron impact on O_2 has been measured under collisionless conditions in cryogenic LABCEDE. Relative cross sections for the emission of short wavelength infrared and medium wavelength infrared radiance from highly excited O atoms formed in irradiated O_2 have been measured. The distribution of population over the high-lying states of O in irradiated O_2 has been determined. These measurements provide important inputs to the interpretation of nuclear test observations and to code predictions of nuclear plasma plume infrared emissions. Measurements currently underway include the investigation of the excitation and quenching of infrared emissions from N_2, CO_2, and O_3.

COCHISE: This helium-cooled cryogenic facility (Cold Chemiexcited Infrared Simulation Experiment) utilizes state-of-the-art detection technology being developed for space surveillance systems. The helium cooling allows cryopumping and background suppression, which results in extremely sensitive "wall-less" conditions. A reaction vessel and spectrometer inside the cryogenic chamber are the main active components. Internal microwave discharge sources create radical species which are cross-mixed with reactants in a reaction region observed with a cryogenic spectrometer. This permits the observation of emission from excited species with number densities as low as 10^6 cm^{-3}.

Recently, data have been collected on the spectral extent of the emission from excited electronic states of the nitrogen molecule (N_2^*), created in the microwave discharge. The branching ratio of emission from common excited states has been determined. The N_2^* spectrum is shown in the figure. These emission lines fall within the 2 to 4 μ region, a candidate region for detecting and tracking cold (300°K) targets in space.

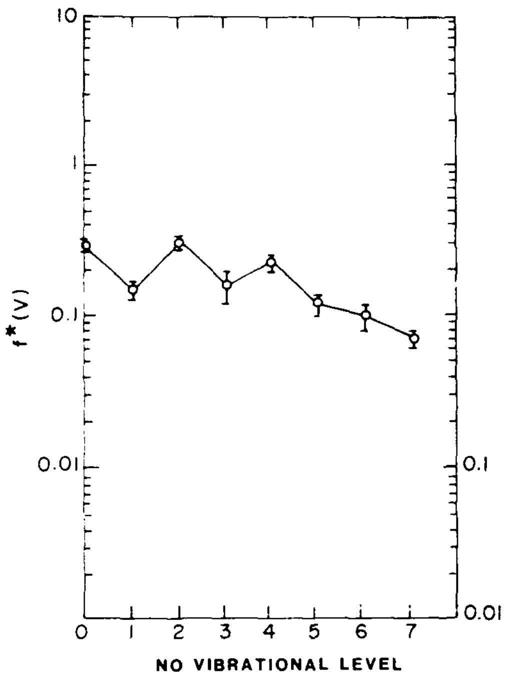
A new detector, a solid state photomultiplier, is presently being tested in COCHISE. This detector has the potential of increasing the signal-to-noise ratio of this already sensitive facility by approximately a factor of 100. This would contribute significantly to the detection of weak emissions in the window regions and provide a means of measuring the relative lifetimes of excited molecular states.



Short Wavelength Infrared Emission Spectrum Observed from Discharged Ar/N_2 with Ar Counterflow under Conditions of High N_2 Flow. (Resolution is 0.013 μm. The flow conditions were 2500 μmole per second Ar and 250 μmole per second N_2 through the discharge and 2700 μmole per second Ar through the counterflow.)

FACELIF: Laser spectroscopic techniques are applied to a standard flow-tube kinetics apparatus (Flowing Atmospheric Chemistry Experiment with Laser-Induced Fluorescence) to investigate detailed atmospheric chemical pathways. Multiphoton ionization utilizing a Nd:YAG pumped dye laser and nonlinear mixing make this instrument an extremely sensitive room-temperature technique for active probing of vibrational distributions of product molecules. This apparatus has been used to investigate the distribution of vibrational states of NO formed in the reaction $N(^4S) + O_2 \rightarrow NO(v) + O$. The relative populations of NO(v) have been determined and are shown in the figure.

A second experiment involving a color center laser has determined an upper limit of 20:1 on the branching ratio of the CO_2



Relative Population of Nitric Oxide Vibrational Levels Formed in the Reaction of N(4S) + O_2

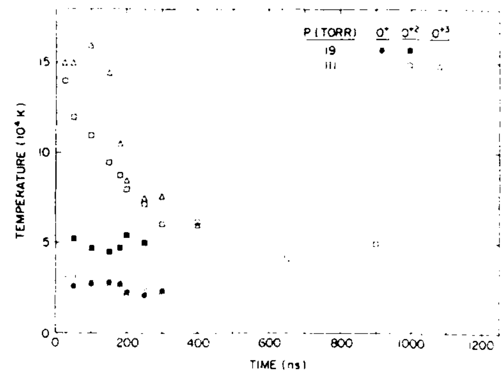
Emission from Several 4.3 μ Bands of CO_2, with Preliminary Spectral Modeling.

combination band radiation in the infrared at 2.7 μ and 4.3 μ. The 4.3 μ emission of CO_2 is compared with a spectral model of the emission in the next figure.

LINUS: In the LINUS (Laser Induced Nuclear Simulation) program, laser-induced breakdown of gases is used to investigate the production of infrared, visible, and ultraviolet radiation from a recombining plasma. An important source of bright-line emissions in the upper atmosphere is a nuclear explosion. The data obtained during the nuclear weapons test series cover a limited spectral range, and virtually no information is available on the details of the infrared emissions. The objective of the LINUS program is the investigation of the infrared, visible, and ultraviolet wavelength-emission processes in a laboratory laser-produced plasma to determine the spectral emissions from high-altitude nuclear plasma plumes. These laboratory measurements are required, first, to validate the infrared predictions of nuclear plasma-emission models, and, second, to permit extrapolation of the nuclear test data to the infrared.

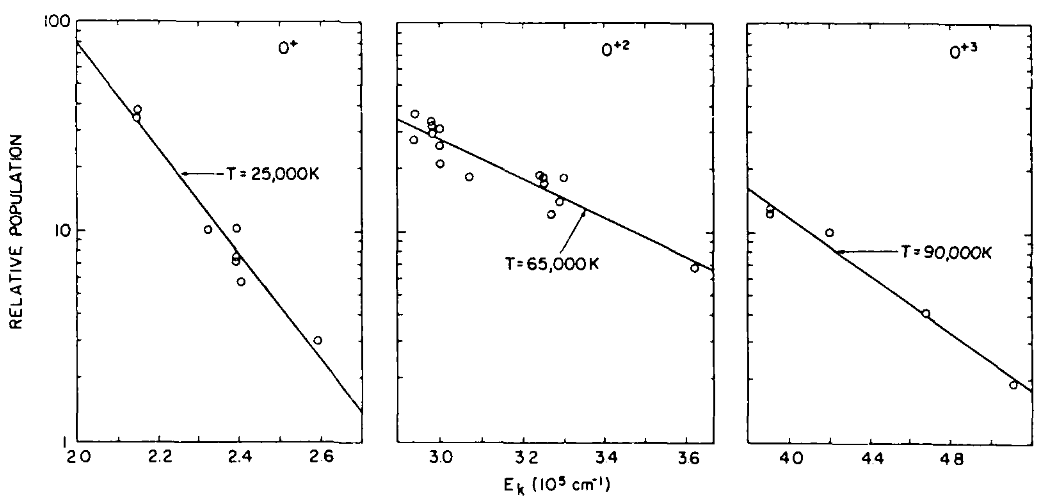
The production of a recombining plasma is achieved in the LINUS facility by tightly focusing the output of a high-powered, pulsed Nd: YAG laser into a target gas cell. The energy density in the focal region is sufficient to cause gas breakdown and generate a brightly emitting plasma of atomic constituents and electrons. Power intensities approaching 1 gW cm^{-2} can be achieved in the focal volume, resulting in temperatures in excess of 100,000°K. The light from this plasma is gathered, resolved spectrally and temporally, and detected.

The short and medium wavelength infrared emissions from a recombining laser-produced oxygen plasma have been measured using the LINUS apparatus. These measurements were made to determine infrared line positions and strengths, which are required by nuclear plasma-emission models. Emissions from high-lying atomic oxygen states generated by ion-electron recombination were observed. Strong emission features were identified at 1.8, 2.7, 3.3, and 7.5 μ. These results indicate that highly excited neutral oxygen atoms are potentially bright infrared emitters in high-altitude nuclear airbursts. Bright emissions from highly excited oxygen atoms are predicted in the long wavelength infrared, and LINUS measurements will be made to determine line strengths and to provide an experimental benchmark for testing of the nuclear plasma-emission model.



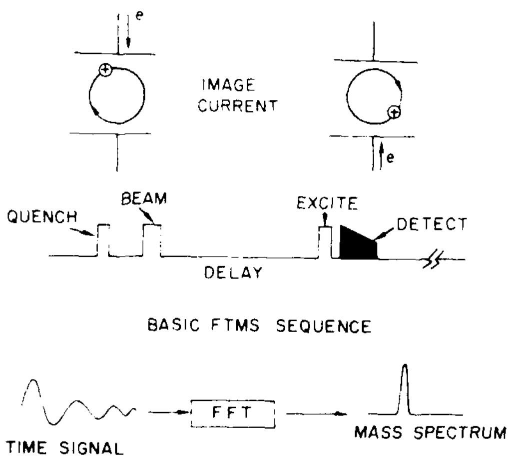
Time Dependence of O^{+n} Spectroscopic Temperatures Determined Using the LINUS Facility.

Time-resolved measurements of visible wavelength emissions have been made for several target gas pressures to correlate infrared and ultraviolet/visible emissions. These results will permit the extrapolation of the ultraviolet/visible nuclear test data to the infrared and the determination of a synthetic infrared spectrum predicting the emissions from a nuclear plasma plume. The LINUS spectra show bright emission features from excited states of singly and multiply charged ions of atomic oxygen at early times following laser plasma initiation. Since these ions are the precursors for neutral atomic oxygen, analysis of the processes producing these excited states is necessary for a complete understanding of the infrared radiance of the plasma. Spectroscopic temperatures were obtained for O^+, O^{+2}, and O^{+3} from fitting the



Determination of O^{+n} Spectroscopic Temperatures in the LINUS Experiment for P = 55 Torr and t = 20 ns.

observed emission intensities to the Boltzmann formula as shown in the figure. While emissions from several electronic states for each species were used in the analysis, the spectrum of a given oxygen charge state was determined to be characterized by one spectroscopic temperature for a specific pressure and time after plasma creation. As shown in the figure, the LINUS measurements indicate that the different charge states of oxygen are not in equilibrium in the plasma and that the higher charge states cool very quickly at higher pressures whereas the lower charge states (O and O^+) do not cool.



Top: Positive Ion in Its Cyclotron Orbit and Its Image Current. Middle: Basic Fourier Transform Mass Spectrometer Experimental Sequence Resulting in a Time Domain Signal. Bottom: Transformation of Signal into Mass Spectrum.

Laboratory measurements of the infrared, visible, and ultraviolet emissions from a recombining laser-produced oxygen plasma have been made using the LINUS facility. These measurements are necessary to characterize the line emissions produced by a high-altitude nuclear plasma plume. LINUS provides input for nuclear plasma model validation and nuclear test data interpretation.

FTMS: A Fourier transform mass spectrometer used to conduct a variety of experiments involving ions of atmospheric gaseous species has been applied to study the reaction of negative ions with some atmospheric molecules to determine branching ratios for formation of the lighter negative ions. The capability of the instrument to simultaneously measure all the ionic species, and provide the time history of each of those species, is a unique feature of the instrument (see the figures).

The principal part of the apparatus is a cubical cell with six insulated sides placed in a homogeneous magnetic field. Ions are created by electron bombardment or electron attachment in the cell and are allowed (during a delay time) to react with other molecules to produce new ionic species. The desired ions are then elevated to their cyclotron orbit. An image current induced by these ions is then measured, digitized, and Fourier-transformed to obtain the mass spectrum. Measurement of the intensities then allows the deduction of the rate constants for the reactions.

During this reporting period a critical study has shown that if appropriate precautions are not taken erroneous rate constants can be deduced. The problem arises from the fact that good spectra require large numbers of data points in the time domain. During the necessary observation time, ions of different masses decay at different rates and consequently incorrect relative ion intensities are obtained. This problem has been alleviated in two different ways. The first method in-

AFGL Fourier Transform Mass Spectrometer (FTMS) and Dedicated Signal Processing System.

volves the application of maximum entropy for deducing spectra. This method requires very few data points and the spectrum is obtained literally immediately and before the decay is consequential. The second method employs the frequencies obtained by fast Fourier transform or maximum entropy in a least-squares program to fit a short data segment from the time-domain signal.

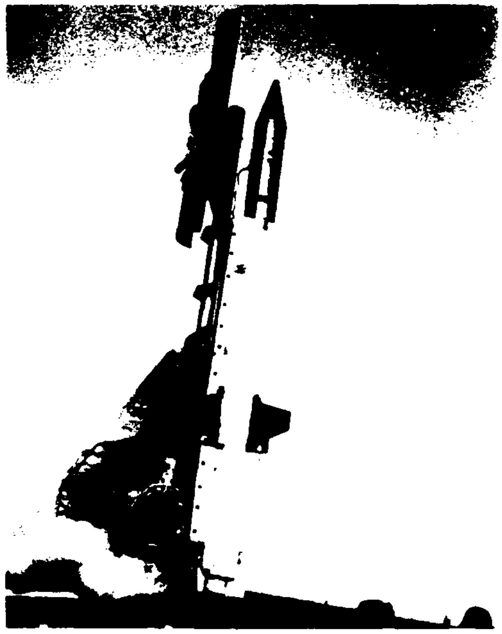
The very new application of the maximum entropy method to FTMS time signals continued in this reporting period with the aim of obtaining super high mass resolutions. The judicious application of the method has produced some very astounding resolutions: a $m/\Delta m$ of 10 million was recently recorded at mass 28 amu.

The capabilities of the FTMS apparatus were also recently expanded to provide a method to perform experiments on ion/molecule reactions at elevated energies in the range up to 10 eV to study the effect of kinetic energy upon reaction rates. This improvement has required some hardware and software modifications which are already in place and will be used to study the reactions of N^+ with O_2 and O^+ with CO_2.

INFRARED ATMOSPHERIC ROCKET PROBES

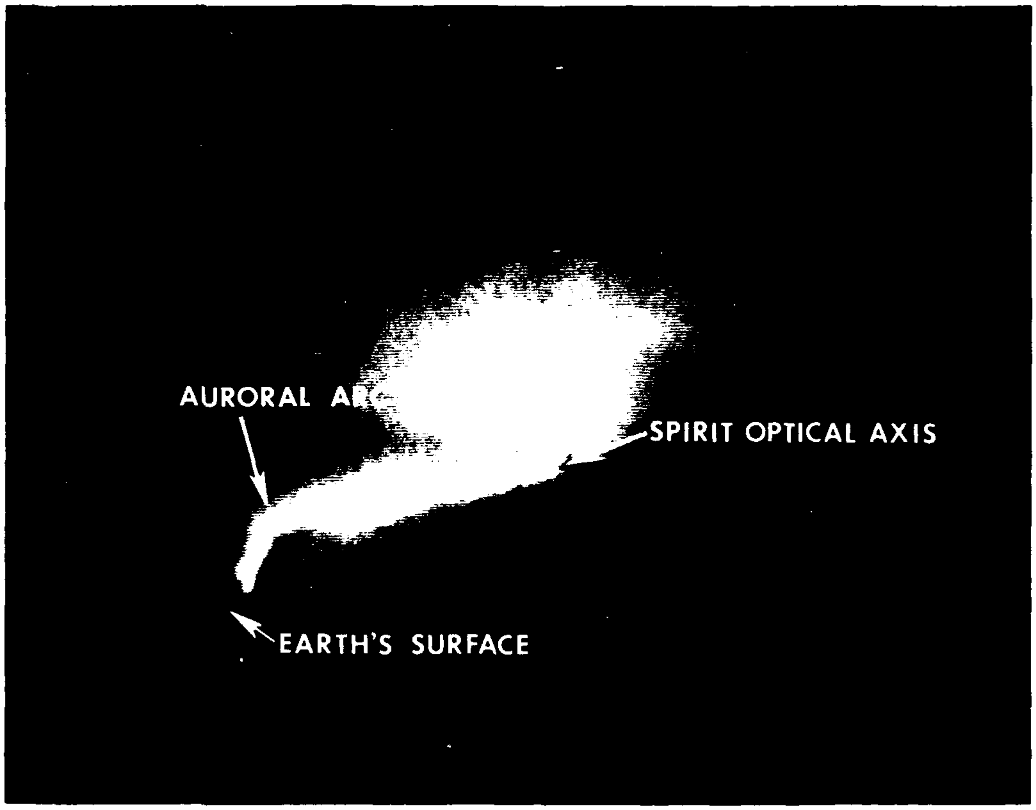
Sounding rocket experiments are performed to determine the intensities and spectral signatures of atmospheric backgrounds from quiescent and aurorally disturbed atmospheres. The objective of these experiments is to identify the specific electronic states and vibrational levels of the radiating species and to characterize the production and radiative and collisional loss processes to allow computer codes to adequately predict background signatures for surveillance systems in ambient and aurorally disturbed backgrounds.

The SPIRIT I rocket probe measured the spectral infrared emissions from a bright aurora in the earth-limb viewing geometry. The primary instrument was a multi-detector, cryogenic Michelson interferometer mated to a cold telescope with high off-axis rejection to facilitate observation of upper atmospheric emissions and discriminate against the much brighter infrared radiation from the earth's surface. The payload was launched from Poker Flat Research Range, Alaska, at 0942 GMT, April 8, 1986 (see the figure).



SPIRIT Rocket Payload in Launch Configuration at Poker Flat Rocket Range near Fairbanks, Alaska. (The shroud covering the rocket motors maintains the temperature of the rocket fuel at approximately 20 °C. The split cylindrical shell minimizes contamination of the payload surface and spurious sources of infrared emission.)

Observations were made of the earth-limb atmosphere, which contained active discrete auroras with measured brightness as high as 180 kilorayleighs of atomic oxygen green line emission (see the figure). About 140 spectral scans were obtained, most had a spectral resolution of 8 wavenumbers, but some were obtained with a spectral resolution of 1 wavenumber. The spectral range of the SPIRIT I interferometer spectrometer is 400 to 2500 wavenumbers. Ground-based measurements were made from Fort Nelson, Canada, in support of the rocket experiment. This location was the region of the tangent point of the earth-limb viewing sensor. Ancillary rocket-based instruments included a video camera to provide real-time imaging of the field-of-view (FOV) for ground-controlled pointing, two cameras (one for high-resolution imaging of the FOV and one for celestial aspect information), and an infrared horizon sensor.



Observation of Earth Limb Auroral Emissions Showing Intense Discrete Aurora Recorded by Video Camera on SPIRIT Rocket Payload.

Preliminary analysis of the data has shown general agreement with model computations for the dominant long wavelength infrared atmospheric emissions of carbon dioxide at 15 μ, and ozone at 9.6 μ near the band peaks for these emissions. However, SPIRIT is anticipated to provide unique insight into infrared atmospheric emissions at other wavelengths where the present understanding has been limited because of a lack of experimental data.

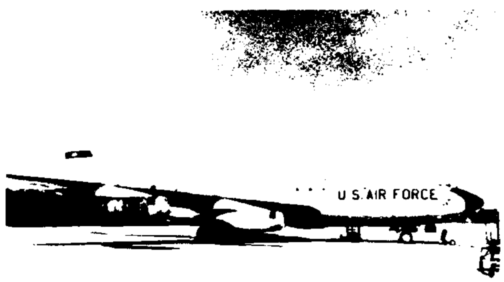
A second rocketborne experiment, designated HIRAM (High Resolution Auroral Measurement), is being readied for a field campaign to take place during the February through April, 1987, time frame from the Poker Flat, Alaska, rocket range. HIRAM is designed to obtain infrared spectral measurements of a bright aurora in a zenith-viewing configuration. The primary instrument is a cooled Michelson interferometer with a spectral range of 1300 to 4300 wavenumbers, a spectral resolution of 1.1 wavenumbers, and a spectral sensitivity of 3 × 10[illegible] Watts/cm2/sr/cm-1. Ancillary instruments include four 3914 Å photometers, an atomic oxygen detector, and an energy-deposition scintillation detector to monitor the flux of energetic particles. This experiment has the advantage of measuring *in-situ* auroral particle flux and atomic oxygen density to support interpretation of the auroral emissions in terms of atmospheric processes.

EXCEDE III is a rocketborne experiment which is similar to SPIRIT I and HIRAM. It measures emissions due to electron impact excitation of atmospheric species. In this case, however, the excitation is due to a 120 kW electron beam (3 kV, 40 A) generated on one of two experiment payload modules. The payloads will be carried to an apogee of 120 km by an ARIES rocket. After payload separation (orthogonal to the trajectory plane), the accelerator module will maneuver to point the electron beam up the geomagnetic field lines and the sensor module will maneuver to point the primary FOV's at the beam with an elevation angle of 38°. On downleg the beam will shorten as the atmospheric density increases. The primary FOV's will intersect the beam at a point about 95 meters from the gun module when the electron accelerator begins to operate. This distance will increase along the electron beam as the sensor module continues to drift away from the gun module with a constant separation velocity. The electron beam will pulse with a 4-second-on/2-second-off format, allowing the spectral sensors to complete one or more scans of both electron-induced and ambient atmospheric emission. As the beam moves across the field lines, it leaves behind it a highly excited region with ion densities on the order of 3×10^{6} cm^{-3}. This region is referred to as the "afterglow" region; long-lived species will radiate with their characteristic production time or radiative lifetime as modified by quenching by other species.

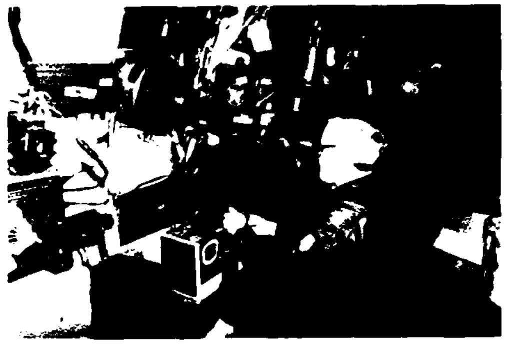
The primary instruments include a 2-22 μ interferometer with a 2 wavenumber resolution, a 2.5-20 μ circular variable filter (CVF) spectrometer with a 2 percent resolution, an infrared spatial radiometer at 2.7 and 4.3 μ with 0.2 degree spatial resolution, and ultraviolet and visible spectrometers covering the range from 0.13 to 0.80 μ with about 0.001 μ resolution. Other rocket-payload instruments include spatial scanning filter photometers with bandpasses at 0.3914, 0.3804, 0.5577, and 0.2761 μ. Two 2.5-20 μ CVF spectrometers are pointed at 8 and 20 degrees into the afterglow region. A staring photometer with bandpasses at 0.5200 and 0.5228 μ will be pointed 18° into the afterglow. The photometers filtered at specific wavelengths observe transitions from excited states with well-defined production and loss processes to assist in the interpretation and analysis of the data. Other sensor module instruments include x-ray detectors to measure beam energy at the primary FOV, video to assist ground-based pointing control of the sensor module as an optional override of the preprogrammed orientation, and cameras to document beam shape and intensify distribution.

In addition to the sensor module instrumentation, a number of photometers and spectrometers will be located on the accelerator module to observe emissions at the base of the beam from within a few meters of the electron source. Other accelerator module instruments include video, cameras, plasma probes, retarding potential analyzers, and an electrostatic analyzer to provide various diagnostics. Extensive ground-based data will also be collected by cameras, video, and photometers. This experiment is scheduled for launch in

1989 into a clear dark night atmosphere from White Sands, New Mexico.



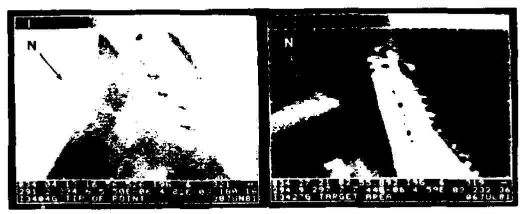
AFGL Flying Infrared Signatures Technology Aircraft.



Adjusting the Tracker's Monitor on a Long Wavelength Infrared Mapper Aboard the Flying Infrared Signatures Aircraft. (The mapper, installed in a 12-inch eyeball mount designed at AFGL, has a 5X telescopic lens. Other infrared mappers and interferometer spectrometers can be seen to the right.)

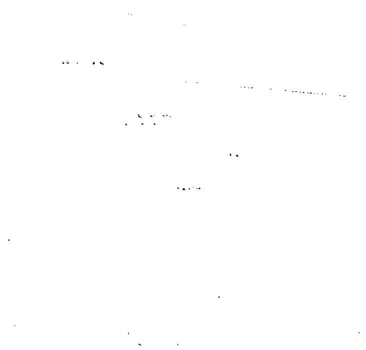
AIRBORNE MEASUREMENTS

The Flying Infrared Signatures Technology aircraft is equipped as a comprehensive laboratory for in-flight research and measurement on the infrared phenomenology of targets and backgrounds. Radiometers, interferometers, spectrometers, and a variety of spatial mappers that produce TV-like images of infrared emissions are used to collect measurements of spectral intensities and thermal images (see the figures).



Infrared Image of the Same Location in the Morning and Afternoon Showing Brightness Changes Due to Solar Heating.

The aircraft range of over 5000 miles permits worldwide deployment, and its ability to fly at altitudes above 40,000 ft allows infrared scientists to study the environment from near sea level to well above the obscuring clouds and above nearly all the atmospheric water vapor. This aircraft is a reliable platform for the study of geographic, seasonal, and diurnal variations of the sky, clouds, and earth. The flights are frequently coordinated with rocket launches and other test aircraft, which work in concert to study a common problem from differing aspects. In recent years a large part of the measurement capability has been employed to understand the in-flight infrared characteristics of aircraft. Unique measurements of the infrared radiation of the boost phase of missile launches have been obtained from this aircraft. The important



Modeled Infrared Components that Contribute to Total Image Brightness of a Target and Total Apparent Brightness as Seen by Distant Observer.

role that the surrounding environment of land, sea, clouds, and atmosphere plays in influencing target infrared behavior, or "signature," is being determined in detail (see the figure). The data obtained are used to develop new models that can simulate infrared behavior and to validate and test specific theoretical and laboratory-based models (see the figure).

As infrared technology has made large advances in recent years, the need for understanding the behavior and appearance of targets at high spatial resolutions and from long measurement ranges has become important. New complex infrared mosaic and scanning sensors introduce a whole new class of problems to be solved so that these instruments can be used successfully in weapon seekers, surveillance systems, and for intelligence gathering by remote sensing. The Flying Infrared Signatures Technology aircraft provides an important platform from which to test new sensor concepts and to obtain detailed infrared images of targets and backgrounds so that new systems can achieve their development goals.

The aircraft has a variety of unique instrumentation. Five Michelson interferometers provide high-resolution spectral data. These instruments, when mounted in a special "eyeball" window, can look out the side of the aircraft over a wide range of angles. A gold-coated periscope mirror can also be inserted through the eyeball into the ambient airstream, allowing viewing in any direction simply by rotation of the periscope. This combination of mounts permits a target to be viewed anywhere in the hemisphere on the right side of the aircraft.

Three different kinds of thermal-imaging scanners are available to be operated simultaneously with the spectral-measuring interferometers. The imaging systems produce TV-like images from infrared radiation in the 2 μ to 14 μ spectral region. Two systems use an array of HgCdTe or InSb detectors to provide spatial data in a scene and to resolve temperature differentials less than 0.1°C. When mounted behind 7-in. aperture optics, these sidelooking systems have a spatial resolution of better than 0.3 mrad. A third system using a Schottky barrier PtSi mosaic array with more than 30,000 detector elements has been developed for the aircraft. It will eventually be sensitive in the 1.0 to 5.0 μ region. These systems provide absolutely calibrated radiometric imagery in the infrared.

The airborne infrared measurements program collects large amounts of data from a variety of backgrounds and targets. Spectral and spatial data have been collected from desert, urban, cultivated, forested, mountain, snow, cloud, and water backgrounds. Special flights have been used to measure the scattering and transmission of clouds when viewed from above, below, and through a variety of clouds. Flights have been made over selected terrain throughout the day to determine the diurnal variation of its infrared characteristics. A wide variety of targets have been measured. A forest fire from which the sensitive interferometers were able to detect large amounts of carbon monoxide was measured at a range of many miles. More than thirty types of aircraft have been measured over power settings from idle to maximum thrust and from 500 ft to 40,000 ft flight altitudes. Industrial sites, tanks, and ships have also been measured from a variety of flight altitudes.

MODELING

Theoretical models are being developed of infrared emission from the quiescent as well as the aurorally disturbed upper atmosphere, called the Atmospheric Radiance Code (ARC) and the Auroral Atmospheric Radiance Code (AARC). These models are being validated by analysis of data from the field experiments.

The completion of the first version of AARC has greatly facilitated our ability to analyze infrared auroral field data and perform simulations that are needed in planning field activities. This user-friendly, menu-driven code enables fast efficient study of the dependence of auroral radiance upon many different geophysical properties, such as dosing strength, the energy spectrum of the precipitating electron flux, and minor-species concentrations.

Repetitive runs with slightly different conditions have given us much insight into the impact of the observation geometry on the observed spectral radiance. A case in point is the observation of the optically thick CO_2 4.3-μ radiance. The figure shows the geometry of two equivalent auroral arcs that are symmetrically placed about

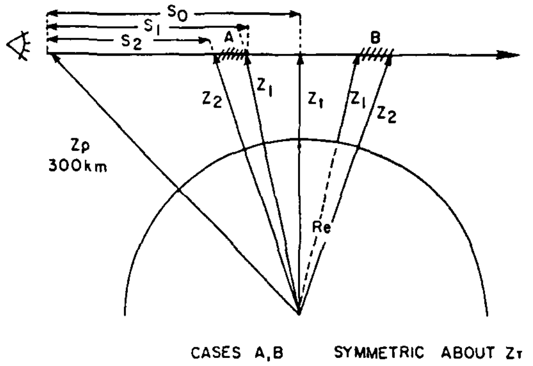
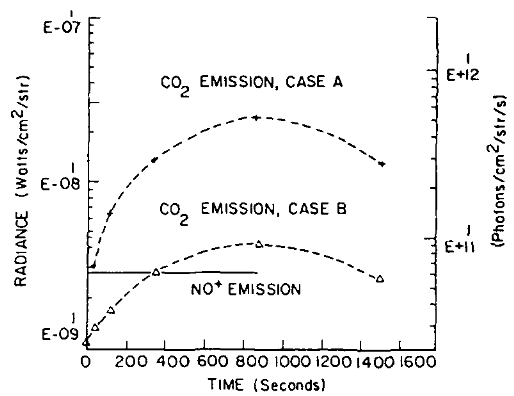


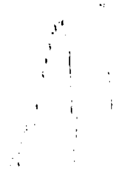
FIGURE CAPTIONS

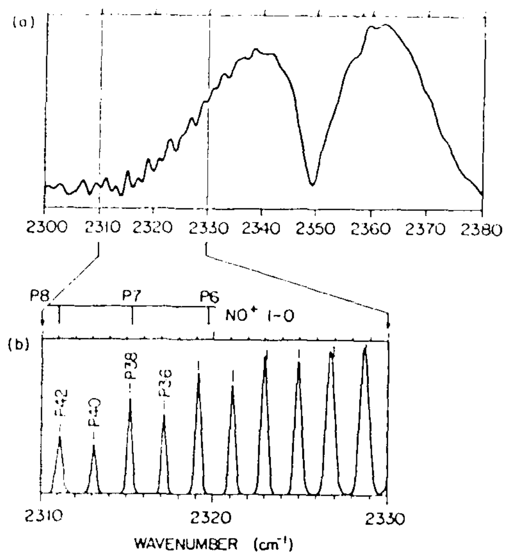
Schematic Diagram of Limb-Viewing Geometry Used for Calculations of Total CO_2, v_3 and NO^+ Fundamental-Band Radiance for Two Equivalent Auroral Arcs with IBC III Auroral Arc at Either Path Segment A or Path Segment B Located Symmetrically about Tangent Point. (Parameter values are z_t = 100 km, z = 104 km, and z_2 = 109 km.)



Total CO_2, v_3 and NO^+ Fundamental-Band Radiance for Cases A and B. (The optically thin NO^+ radiance is the same for both cases. An IBC III aurora doses the atmosphere for 900 seconds and then is abruptly turned off.)

the tangent point (case A and case B). The next figure shows the time history of the





Apodized Auroral Spectrum from Field Widened Interferometer (FWI), Showing CO_2 4.3 μm Band Emission, and Expanded Portion of Spectrum after Application of Nonlinear Deconvolution, Showing Resolution Enhancement. (Chance coincidences of some NO^+ lines with CO_2 P-Branch lines are indicated.)

Comparison of Auroral Atmospheric Radiance Code and Field-Widened Interferometer Data for Zenith View from 100 km Altitude in Region of CO_2 4.3 μm Band.

total CO_2 4.3-μ radiance for the two cases, after a sudden onset of the aurora. In case B, the path to the observer is optically thicker, since the dosing region is farther from the observer, and the radiance is almost an order of magnitude weaker. This is in contrast to an observer measuring an optically thin emission (such as 3914 Å or the 4.3-μ $NO^+(v)$ emission shown by the solid line in the previous figure), where the radiance observed is the same for both cases. Cases A and B also differ spectrally, with up to 40 percent of the radiance originating from isotopic and hot bands in the optically thicker case B compared to about 10 percent for case A. This is true in spite of the fact that the radiating states for these bands have only 2 percent of the total population.

Although it is not always possible to distinguish the CO_2 4.3-μ radiance from the $NO^+(v)$ radiance spectrally, it is important to model them separately since they are produced by distinctly different mechanisms. The $NO^+(v)$ radiance is produced by fast ion - molecule reactions initiated by the precipitating flux. Thus, this prompt emission will mirror the structure of the precipitating flux. The CO_2 radiance is produced by the slow transfer of vibrational energy from N_2 vibration to the asymmetric stretch (ν_3) mode of CO_2, a process that delays the emission by many minutes above 100 km altitude and thus averages over a lot of the structure that is present in the precipitating electrons.

AARC has also been used to analyze the 4.3-μ CO_2 emission measured in the zenith-viewing rocketborne Field-Widened Interferometer (FWI) auroral experiment. The figure shows preliminary results for the AARC model and FWI observed radiance for a zenith view from an altitude of 100 km. Although the match is not perfect in this case, the shape of the band is correct, and the strength in the model can be adjusted by changing any number of input parameters (not measured during the experiment) within reasonable ranges.

A large amount of modeling has also been carried out to date on other radiating species, mostly with the AARC auroral code, in an attempt to understand the FWI data. The radiating species modeled include the nitric oxide fundamental and overtone vibration-rotation bands near 5.3 and 2.7 μ, the 4.3-μ NO^+ fundamental, and the CO vibrational fundamental at 4.8 μ. This modeling is continuing with special emphasis on the interesting delayed emission from the CO_2 bands mentioned in the previous paragraph. In addition to its use in analyzing field data, the AARC model is also useful in the experiment definition phase of a field program. For example, a reflight of the FWI under auroral conditions, known by the acronym HIRAM, is planned for February, 1987, and the AARC model has been used to establish the launch criteria for the HIRAM probe.

In addition to modeling studies of FWI data, much information about the auroral atmosphere and about auroral infrared emissions has been obtained using sophisticated data-analysis techniques on the FWI data and an active investigation of such techniques is currently underway. These include linear and nonlinear least-squares fitting techniques, linear filtering, maximum-entropy spectral analysis, and constrained nonlinear deconvolution (CND) techniques. An example of CND results obtained with the FWI data is shown in the figure. The top panel in the figure is the spectrum of the CO_2 ν_3-band emission (apodized with a triangular window function). The bottom panel is an expanded portion of the deconvolved spectrum, showing resolution enhancement by a factor of four. The alternation in the intensity of the deconvolved CO_2 lines is thought to be evidence for the existence of NO^+ lines in this region; the known positions of three of the NO^+ lines are shown in the top part of the panel. Overall, however, the evidence for NO^+ in the FWI data is inconclusive. A more definitive investigation of auroral NO^+ should be available from the HIRAM data to be obtained in 1987, coupled with further calculations using the AARC model and further exercise of powerful data-analytic tools.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

CALEDONIA, G.E., GREEN, B.D. (Physical Sciences, Inc., Andover, MA); and NADILE, R.M. (AFGL)
The Analysis of SPIRE Measurements of Atmospheric Limb $CO_2(\nu_2)$ Fluorescence
J. Geophys. Res. 90 (1 October 1985)

CHUNG, S., LIN, C.C. (Univ. of Wisconsin, Madison, WI); and LEE, E.T.P. (AFGL)
Transition Probabilities of OI Spectral Lines
J. Quantitative Spectroscopy and Radiative Transfer 36 (1986)

FRANKEL, D.S., GERSH, M.E. (Aerodyne Research, Inc., Billerica, MA); MCINTYRE, A., HUFFMAN, R.E., and PAULSEN, D. (AFGL)
Aries Rocket Motor Infrared and Ultra-violet Spent-Stage Emission
J. Spacecraft and Rockets 22 (September-October 1985)

HAALAND, P. (Air Force Wright Aeronautical Laboratories, Dayton, OH); and RAHBEE, A. (AFGL)
The Molecular Silane Cation
Chem. Phys. Lett. 114 (15 March 1985)

KEMP, J., WELLARD, S., GOODE, D. (Utah St. Univ., Logan, UT); and HUPPI, R. (AFGL)
Cryogenic Michelson Interferometer Spectrometer for Space Shuttle Application
Proc. SPIE 30th An. Tech. Symp. (17-22 August 1986)

LURIE, J., and BAIRD, J.C.
Medium-Wavelength Infrared Emission from a Laser-Produced Oxygen Plasma: Observations of OI 6h ^{2}H at 7.5 μm
Chem. Phys. Lett. 125 (11 April 1986)

LURIE, J.B. (Aerodyne Research, Inc., Billerica, MA); MILLER, S.M., BLUMBERG, W.A.M. (AFGL); and ARMSTRONG, R.A. (Mission Research Corp., Nashua, NH)
Short Wavelength Infrared Line Emission in a Laser-Produced Oxygen Plasma
Chem. Phys. Lett. 120 (18 October 1985)

PIPER, L.G., GREEN, B.D. (Physical Sciences, Inc., Andover, MA); BLUMBERG, W.A.M., and WOLNIK, S.J. (AFGL)
N_2^+ Meinel Band Quenching
J. Chem. Phys. 82 (1 April 1985)
Electron-Impact Excitation of the N_2^+ Meinel Band
J. Atomic and Molecular Phys. 19 (November 1985)

RAHBEE, A.
Application of Maximum Entropy Spectral Analysis to Fourier Transform Mass Spectrometry
Chem. Phys. Lett. 117 (21 June 1985)
High Resolution Mass Spectrometry Using Maximum Entropy Method
Internat. J. Mass Spectrometry and Ion Processes 72 (1986)
Maximum Entropy Method in Fourier Transform Mass Spectrometry
Proc. An. Conf. on Mass Spectrometry and Allied Topics (June 1986)
Calculation of the Ion Intensities by the Least Squares Fit of the Time Signal from FTMS
Fourier Transform Ion Cyclotron Resonance Newsletter (November 1986)

RAWLINS, W.T., GELB, A. (Physical Sciences, Inc., Andover, MA); and ARMSTRONG, R.A. (AFGL)
Infrared Spectra (2-16 μm) of ArI Rydberg Emission from a Discharge Plasma
J. Chem. Phys. 82 (15 January 1985)

RAWLINS, W.T., CALEDONIA, G.E. (Physical Sciences, Inc., Andover, MA); GIBSON, J.J., and STAIR, A.T., JR. (AFGL)
HIRIS Rocketborne Spectra of Infrared Fluorescence in the $O_3(\nu_3)$ Band Near 100 km
J. Geophys. Res. 90 (1 March 1985)

SHARMA, R.D. (AFGL); and WINTERSTEINER, P.P. (Arcon Corp., Waltham, MA)
CO_2 Component of Daytime Earth Limb Emission at 2.7 Micrometers
J. Geophys. Res. 90 (1 October 1985)
Emission from CO_2 Around 2.7 Micrometers from Daylit Atmospheres
Proc. Mtg. of IRIS Specialty Group on Targets, Backgrounds and Discrimination (12-14 February 1985)

STAIR, A.T., JR., SHARMA, R.D., NADILE, R.M. (AFGL); BAKER, D.J. (Utah St. Univ., Logan, UT); and GRIEDER, W.F. (Boston Coll., Newton, MA)
Observations of Limb Radiance with Cryogenic Spectral Infrared Rocket Experiment
J. Geophys. Res. 90 (1 October 1985)

STEARNS, J.R., ZAHNISER, M.S., KOLB, C.E. (Aerodyne Research, Inc., Billerica, MA) and SANDFORD, B.P. (AFGL)
Airborne Infrared Observations and Analyses of a Large Forest Fire
J. Appl. Opt. 25 (1 August 1986)

WINICK, J.R., PICARD, R.H., SHARMA, R.D., and NADILE, R.M.
Oxygen Singlet Delta 1.58-Micrometer (0-1) Limb Radiance in the Upper Stratosphere and Lower Mesosphere
J. Geophys. Res. 90 (1 October 1985)

ZACHOR, A.S. (Atmospheric Radiation Consultants, Inc., Acton, MA); and SHARMA, R.D. (AFGL)
Retrieval of Non-LTE Vertical Structure from a Spectrally Resolved IR Limb Radiance Profile
J. Geophys. Res. 90 (1 January 1985)

ZACHOR, A.S. (Atmospheric Radiation Consultants, Inc., Acton, MA); SHARMA, R.D., NADILE, R.M., and STAIR, A.T., JR. (AFGL)
Inversion of a Spectrally Resolved Limb Radiance Profile for the NO Fundamental Band
J. Geophys. Res. 90 (1 October 1985)

PRESENTATIONS AT MEETINGS JANUARY, 1985 - DECEMBER, 1986

AHMADJIAN, M., Capt., WISE, J.O. (AFGL); and MIRANDA, H.A. (Epsilon Lab., Inc., Burlington, MA)
Particle Analysis Cameras for Shuttle (PACS)
Space Shuttle Experiment and Environment Wkshp., Henniker, NH (6-10 August 1985)

BLUMBERG, W.A.M. (AFGL); and GREEN, B.D. (Physical Sciences, Inc., Andover, MA)
Excitation of IR Emissions from Triplet and Quintet States of Atomic Oxygen
AGU Mtg., San Francisco, CA (8-12 December 1986)

BLUMBERG, W.A.M., WOLNIK, S.J. (AFGL); and GREEN, B.D. (Physical Sciences, Inc., Andover, MA)
Production of Highly-Excited Triplet and Quintet States of Atomic Oxygen
AGU Mtg., San Francisco, CA (9-13 December 1985)

BLUMBERG, W.A.M., IP, P.C.F. (AFGL); GREEN, B.D., MARINELLI, W.J., and CALEDONIA, G.E. (Physical Sciences, Inc., Andover, MA)
Electron Beam Growth in Thin N_2 Targets
APS Sixteenth An. Mtg. of the Div. of Electron and Atomic Physics, Norman, OK (29-31 May 1985)

DEFACCIO, M.A., RAWLINS, W.T., FRASER, M.E. (Physical Sciences, Inc., Andover, MA); and MILLER, S.M. (AFGL)
Vibrational and Rotational Excitation of CO by Energy Transfer from Metastable Nitrogen
AGU Mtg., San Francisco, CA (8-12 December 1986)

FRASER, M.E., RAWLINS, W.T., MURPHY, H.C., DEFACCIO, M.A. (Physical Sciences, Inc., Andover, MA); and MILLER, S.M. (AFGL)
Infrared Spectroscopy of the $W^3\Delta \rightarrow B^3\pi$ and $W^1\Delta \rightarrow a^1\pi$ Systems of Nitrogen
AGU Mtg., San Francisco, CA (8-12 December 1986)

GREEN, B.D., MARINELLI, W.J. (Physical Sciences, Inc., Andover, MA); and BLUMBERG, W.A.M. (AFGL)
Laboratory Observations of N_2 Electronic Emissions Between 180 NM - 5 Microns
AGU Mtg., Baltimore, MD (27-31 May 1985)
Relative Excitation Efficiencies of N_2 Electronic States
38th An. Gaseous Electronic Conf., Monterey, CA (15-18 October 1985)
Excitation and Quenching of the Lowest Vibrational Levels of N_2 (B) and N_2^+ (A) States
AGU Mtg., San Francisco, CA (9-13 December 1985)

GREEN, B.D., MARINELLI, W.J., PIPER, L.G. (Physical Sciences, Inc., Andover, MA); and BLUMBERG, W.A.M. (AFGL)
Excitation and Quenching of N_2 ($B^3\pi_G$) in Electron-Irradiated Nitrogen
Conf. on the Dynamics of Molecular Collisions, Snowbird, UT (14-19 July 1985)

GREEN, B.D., FRASER, M.E., DEFACCIO, M.A. (Physical Sciences, Inc., Andover,

MA); LEE, E.T.P., and O'NEIL, R.R. (AFGL)
Analysis of the EXCEDE Spectral 2-8 Micron Data
AGU Mtg., San Francisco, CA (8-12 December 1986)

HOWARD, S.J.
Fast Algorithm for Discrete Fourier Spectrum Extrapolation
Optical Soc. of Am. An. Mtg., Seattle, WA (19-24 October 1986)

IP, P.C.F., BLUMBERG, W.A.M. (AFGL); GREEN, B.D., MARINELLI, W.J., and CALEDONIA, G.E. (Physical Sciences, Inc., Andover, MA)
Measurements and Calculations of Electron Beam Growth in N_2
38th An. Gaseous Electronics Conf., Monterey, CA (15-18 October 1985)

JOSEPH, R.A. (Arcon Corp., Waltham, MA); PICARD, R.H., WINICK, J.R. (AFGL); and WINTERSTEINER, P. (Arcon Corp., Waltham, MA)
Analysis of CO_2 $\nu3$ Infrared Emission from the Aurorally Dosed Lower Thermosphere
AGU Mtg. San Francisco, CA (8-12 December 1986)

KEMP, J., WELLARD, S., GOODE, D. (Utah St. Univ., Logan, UT); and HUPPI, R. (AFGL)
Cryogenic Michelson Interferometer Spectrometer for Space Shuttle Application
SPIE 30th An. Tech. Symp., San Diego, CA (17-22 August 1986)

MARINELLI, W.J., GREEN, B.D. (Physical Sciences, Inc., Andover, MA); and BLUMBERG, W.A.M. (AFGL)
Quenching of $N_2(\tilde{a}\ \pi g)$ by N_2
AGU Mtg., San Francisco, CA (9-13 December 1985)
Quenching of the A Singlet Pi State of N_2 by N_2
APS Seventeenth An. Mtg. of the Div. of Electron and Atomic Phys., Eugene, OR (18-20 June 1986)

PICARD, R.H., WINICK, J.R., SHARMA, R.D. (AFGL); and JOSEPH, R.A. (Arcon Corp., Waltham, MA)
Modeling NO and NO^+ Infrared Auroral Emissions
IAGA Symp. on Airglow and Auroral Excitation and Models, Prague, Czechoslovakia (5-17 August 1985)

PICARD, R.H., WINICK, J.R., SHARMA, R.D. (AFGL); ZACHOR, A.S. (Atmospheric Radiation Consultants, Acton, MA); ESPY, P.J., and HARRIS, C.R. (Utah St. Univ., Logan, UT)
Interpretation of Observations of Emission and Absorption of Radiation in the Meso- sphere and Lower Thermosphere
XXVI COSPAR Mtg., Toulouse, France (29 June-13 July 1986)

RATKOWSKI, A.J.
The MAPSTAR Program: Scientific Goals and Overview
AGU Mtg., Baltimore, MD (27-31 May 1985)
The MAPSTAR Program June '84 Campaign
Global Thermospheric Mapping Study Wkshp., Cambridge, MA (10-12 July 1985)
The MAPSTAR Program: Scientific Overview and Preliminary Results
IAF Mtg., Stockholm, Sweden (7-12 October 1985)

RAWLINS, W.T., FRASER, M.E., DEFACCIO, M.A., COWLES, L.M., MURPHY, H.C. (Physical Sciences, Inc., Andover, MA); and MILLER, S.M. (AFGL)
Rovibrational Excitation of Nitric Oxide in the Reaction of Active Nitrogen with Oxygen
AGU Mtg., San Francisco, CA (8-12 December 1986)

SHARMA, R.D. (AFGL); and WINTERSTEINER, P.P. (Arcon Corp., Waltham, MA)
2.7 μm Emission from Water Vapors in the Daylight Atmosphere of the Earth
AGU Mtg., San Francisco, CA (9-13 December 1985)

SHARMA, R.D. (AFGL); HARLOW, H., and RIEHL, J.P. (Univ. of Missouri, St. Louis, MO)
Determination of Atomic Oxygen Density and Temperature of the Thermosphere by Remote Sensing
AGU Mtg., San Francisco, CA (8-12 December 1986)

SMITH, D.R., and RATKOWSKI, A.
Contamination of Rocket-Borne IR Measurements
13th An. Mtg. on Upper Atmospheric Studies by Optical Methods, Lysebu, Oslo, Norway (19-23 August 1985)

STAIR, A.T., JR., and SHARMA, R.D.
Non-LTE IR Emissions of the Upper Atmosphere
IAGA Symp. on Radiation in the Middle Atmosphere, Prague, Czechoslovakia (5-17 August 1985)

UPSCHULTE, B., GREEN, B.D., MARINELLI, W.J. (Physical Sciences, Inc., Andover, MA); and BLUMBERG, W.A.M. (AFGL)
Nitrogen Infrared Electronic Emissions Representative of the Aurora
AGU Mtg., San Francisco, CA (8-12 December 1986)

WINICK, J.R., PICARD, R.H., SHARMA, R.D. (AFGL); and JOSEPH, R.A. (Arcon Corp., Waltham, MA)
Auroral NO Infrared Radiance and the Production Efficiency of NO
AGU Mtg., San Francisco, CA (8-12 December 1986)

WINICK, J.R., PICARD, R.H., SHARMA, R.D. (AFGL); JOSEPH, R.A., and WINTERSTEINER, P.P. (Arcon Corp., Waltham, MA)
Modeling of Auroral Infrared Emission at 4.3 μm
AGU Mtg., San Francisco, CA (9-13 December 1985)
Radiative Transfer Effects on Aurorally Enhanced 4.3 Micron Limb Radiance
XXVI COSPAR Plenary Mtg., Toulouse, France (30 June-12 July 1986)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

DEGGES, T.C. (Visidyne, Inc., Burlington, MA); and D'AGATI, A.P. (AFGL)
A User's Guide to the AFGL/Visidyne High Altitude Infrared Radiance Model Computer Program
AFGL-TR-85-0015 (October 1984), ADA 161432

ESPLIN, M.P. (Stewart Radiance Lab., Bedford, MA); SAKAI, H. (Univ. of Massachusetts, Amherst, MA); ROTHMAN, L.S., VANASSE, G.A. (AFGL); BAROWY, S.M., and HUPPI, R.J. (Stewart Radiance Lab., Bedford, MA)
Carbon Dioxide Line Positions in the 2.8 and 4.3 Micron Regions at 800 Kelvin
AFGL-TR-86-0046 (19 February 1986), ADA173808

LURIE, J.B. (AFGL); and BAIRD, J.C. (Brown Univ., Providence, RI)
Medium- and Long-Wavelength Infrared Emission from a Laser-Produced Oxygen Plasma
AFGL-TR-85-0341 (31 December 1985), ADA169475

MILLER, S.M., LURIE, J.B., ARMSTRONG, R.A. (AFGL); WINKLER, I. (Massachusetts Inst. of Tech., Cambridge, MA); STEINFELD, J.I., RAWLINS, W.T., GELB, A., PIPER, L., CALEDONIA, G.E., NEBOLSINE, P., WEYL, G., and GREEN, B.D. (Physical Sciences, Inc., Andover, MA)
Spectroscopic, Kinetic, and Dynamic Experiments on Atmospheric Species
AFGL-TR-85-0077 (21 March 1985), ADA162691

WINTERSTEINER, P.P. (Arcon Corp., Waltham, MA); and SHARMA, R.D. (AFGL)
Update of an Efficient Computer Code (NLTE) to Calculate Emission and Transmission of Radiation Through Non-Equilibrium Atmospheres
AFGL-TR-85-0240 (20 September 1985), ADA172556

ZACHOR, A.S. (Utah St. Univ., Logan, UT); SHARMA, R.D., WINICK, J.R., and PICARD, R.H. (AFGL)
Analysis of Field-Widened Interferometer Data by Least-Squares and Spectral Deconvolution Methods
AFGL-TR-85-0132 (31 May 1985), ADA165253

CONTRACTOR PUBLICATIONS JANUARY, 1985 - DECEMBER, 1986

KEMP, J., BURT, D., ALLARD, G., and BARTSCHI, B. (Utah St. Univ., Logan, UT)
Applying an Interferometer Spectrometer Aboard the Space Shuttle with a Payload Specialist in the Control Loop
Proc. SPIE 30th An. Tech. Symp. (17-22 August 1986)

CONTRACTOR PRESENTATIONS JANUARY, 1985 - DECEMBER, 1986

KEMP, J., BURT, D., ALLARD, G., and BARTSCHI, B. (Utah St. Univ., Logan, UT)
Applying an Interferometer Spectrometer Aboard the Space Shuttle with a Payload Specialist in the Control Loop
SPIE 30th An. Tech. Symp., San Diego, CA (17-22 August 1986)

CONTRACTOR TECHNICAL REPORTS JANUARY, 1985 - DECEMBER, 1986

ADLER-GOLDEN, S. (Spectral Sciences, Inc., Burlington, MA)
Predicted NO_2 IR Chemiluminescence in the Natural Atmosphere
AFGL-TR-86-0099 (13 May 1986), ADA173812

LIN, C.C., and CHUNG, S. (Univ. of Wisconsin, Madison, WI)
Molecular Reaction Rates
AFGL-TR-85-0262 (28 October 1985), ADA 166518

RAWLINS, W.T., PIPER, L.G., GELB, A., CALEDONIA, G.E., NEBOLSINE, P.E., WEYL, G., MURPHY, H.C., COWLES, L.M., and GREEN, B.D. (Physical Sciences, Inc., Andover, MA)
COCHISE Atmospheric Nitrogen/Oxygen Excitation Studies
AFGL-TR-85-0322 (December 1985), ADA172234

STEINFELD, J., WINKLER, I., PHILLIPS, C.M., SCHWEITZER, E., and VAN ZOEREN, C.
Formation and Deactivation of Vibrationally Excited Atmospheric Molecules
AFGL-TR-86-0116 (27 May 1986), ADA 177410

WINTERSTEINER, P.P., and JOSEPH, R.A. (Arcon Corp., Waltham, MA)
Development of Models for Infrared Emission in the Upper Atmosphere
AFGL-TR-86-0163 (1 May 1985), ADA173633

Installing an AFGL "Quick Look" Seismic Field Station. (The three orthogonal sensors are buried in a shallow pit to minimize wind noise. The digital recorder, protected by a styrofoam box, can be set to begin recording automatically on cassette tapes.)

VII EARTH SCIENCES DIVISION

The Earth Sciences Division performs research in seismology, geodynamics, geology, geodesy, and gravity. This research supports the deployment, operations, and delivery of Air Force weapons with particular emphasis on strategic systems. It also supports the Air Force's mission to verify compliance with nuclear test ban treaties. Instrumentation is designed and produced to measure geophysical phenomena worldwide at varying scales and accuracy levels to meet specific needs. Field work is conducted whenever and wherever necessary. Instrumentation is mounted on a variety of test beds designed to operate on land, in the air, or in space, and data are collected where the organization's experience and theory suggest the need. Theoretical models of geophysical phenomena are developed and cast into a quantitative form for comparisons with observations. Tested mathematical models of geophysical phenomena are produced in formats that are useful in various applications.

During the reporting period, work has been conducted on satellite interferometry with Global Positioning System (GPS) satellites, very long baseline interferometry, absolute gravimetry, high-altitude gravimetry, gravity gradiometry, geopotential modeling, satellite altimetry, and cryogenic inertial instrumentation. The structure and seismic propagation properties of the earth's crust have been investigated for areas of Air Force interest around the globe. Effort has also been applied in vibro-acoustic forecasts for the Air Force Space Transportation System (space shuttle) facilities, low-frequency transmission effects from jet engine suppressors (Hush Houses), and the sonic detection of low-frequency aircraft.

GEODESY AND GRAVITY

Geodesy is concerned with the size, shape, and mass distribution of the earth, and its orientation in inertial space. Geodetic information is a necessary foundation for the accurate determination of positions, distances, and directions for launch sites, tracking sensors, and targets. The geodetic and gravimetric parameters for the earth and geodetic information for positioning not only form the structural framework for mapping, charting, and navigational aids, but are also direct inputs for missile inertial guidance systems. Current geodetic information is inadequate to meet the requirements of future Air Force weapon systems.

The Geodesy and Gravity Branch conducts continuing research and development programs in geometric geodesy and in physical geodesy (gravity). These programs are directed toward improving the fundamental knowledge of the earth's size, shape, and gravity field and the techniques used for determining position, distance, and direction on the earth's surface in terrestrial and inertial three-dimensional coordinate systems.

In programs such as gravity gradiometry and GPS interferometry, AFGL cooperates with the Defense Mapping Agency, the Navy, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration, as well as many other government agencies and universities.

GPS Geodesy: AFGL is continuing development of geodetic techniques for position and distance determination based on radio interferometric phase observations of the L-band carrier signals transmitted by the earth-orbiting NAVSTAR satellites of the Global Positioning System (GPS). GPS interferometry is a three-dimensional method by which the relative position vector (baseline vector) extending between two receivers is determined by analyzing data derived from simultaneous observations at the two ends of the baseline. To exploit this technique, AFGL developed a portable, dual band (L1, L2) receiver for surveying over variable baselines using NAVSTAR carrier signals. No knowledge of the coded GPS message is required, nor is mutual visibility between the ends of the baseline necessary. The goal of this research is to demonstrate that the components of a baseline vector between points on the earth can be determined to an accuracy better than first order geodetic survey accuracy (1 part in 500,000) determined by conventional instruments. A second goal is to establish that radio interferometry can also be utilized to determine satellite orbits with unprecedented accuracy.

Over the 1985-1986 time period, many extensive tests of the AFGL receivers have been conducted independently and in comparison with commercial receivers based on a similar concept. These tests have demonstrated that all three baseline vector components can be estimated accurately. With instruments that used only one of the GPS radio bands (L1), we have obtained accuracies of 1-2 mm for short baselines (1 km), and 1-2 parts per million (ppm) for longer baselines. With dual-band receivers (which can eliminate ionospheric effects on the radio signals), with accurate information on the satellite orbits, and with several hours of observation, the accuracy approaches 0.1 ppm in the horizontal and 0.2 ppm in the vertical. This translates to 1 and 2 cm, respectively, for a baseline 100 km in length. Horizontal accuracy of 1 ppm has been obtained with only 15 minutes observation with dual-band instruments. Baseline accuracy is primarily a function of the quality of the available information on the satellite orbits, of local atmospheric conditions (particularly the wet component of the troposphere), and of the receiving antenna. In all cases, baseline results can be obtained within a few hours after data collection.

To achieve the additional goal of improved satellite orbits, AFGL dual-frequency interferometry receivers were installed at the Haystack Observatory in Massachusetts, the Naval Observatory Timing Substation in Florida, and the Harvard College Observatory station in Texas. These receivers were connected to hydrogen maser frequency standards. For the purposes of this experiment, a fourth receiver (Texas Instruments-4100) was located at Owens Valley, California. These preliminary orbit determination tests using four receivers, placed along known baselines, extended over six days with observations of five NAVSTAR satellites made at 6-minute intervals. The results show uncertainties of orbit determination at the 1-5 m level (1-3 parts in 10^7); postfit residuals were less than 2 cm rms. It should be pointed out that satellite orbits are routinely available from the government with accuracies of 0.5 to 2 parts in 10^6, but by using radio interferometric methods 0.1 part in 10^6 can be achieved. Higher accuracies in orbit determination translate directly into more accurate baseline measurement. Such improvements will enhance the science of geodynamics, allowing precise monitoring of crustal motion along faults or fracture zones in the earth for monitoring or predicting earthquakes.

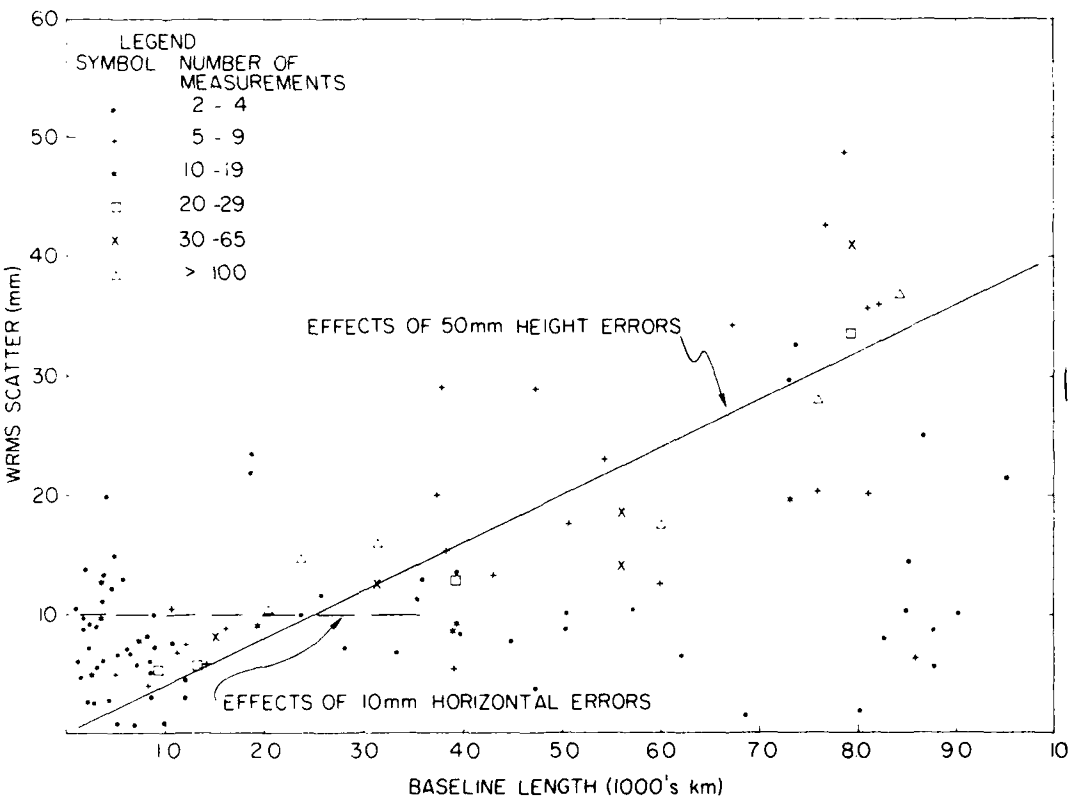
Future efforts in GPS interferometry will concentrate on new techniques to monitor GPS orbits without the necessity of hydrogen masers.

Very Long Baseline Interferometry (VLBI): Satellite radio interferometry is derived from techniques developed earlier from VLBI technology. In VLBI, a plane wave front from a distant quasar source arrives at two radio observatories at different times, depending on the direction of the sources, the orientation of the earth, and the locations of the observatories on the earth. The VLBI technique can precisely determine the time difference by the cross correlation of the signals recorded at the two observatories. As the earth rotates, the time difference changes, and the VLBI data can be used to determine the earth's rotation rate and its irregularities, polar motion, source directions, and the highly precise intercontinental distances between, and relative positions of, the radio observatories.

Currently we are studying the geophysical applications of VLBI, investigating the accuracies of the instrumentation used to obtain VLBI data and the models used to analyze the data, and evaluating the performance of water-vapor radiometers as means of estimating the atmospheric propagation delay due to water vapor.

Over 400 experiments involving measurement of 207 separate baselines are now in the VLBI database. The lengths of these baselines ranged from 1 to 9,500 km. The database contains the following information: the number of baseline determinations; the mean length; the statistical standard deviation of the mean; the weighted root-mean-square (WRMS) scatter of the individual estimates about the mean; the normalized root-mean-square (NRMS) scatter about the mean; the rate of change of the baseline length and its statistical standard deviation; the WRMS and NRMS scatter about the best-fit rate; the interval of time between the first and last measurements for each baseline; and the mean epoch of the measurements.

The statistical properties of the baseline-length determinations are shown in the figure, where the WRMS scatter of the baseline length estimates is plotted as a function of the baseline length. For long baselines (> 2,000 km), this graph shows that the WRMS scatter increases with increasing baseline length, indicating that the baseline-length uncertainty is dominated by errors in the height of the sites at each end of the baseline. The value of the height error inferred from the figure is ~50 mm. The large number of short baselines (< 2,000 km) in this latest solution allows the contribution of the (locally)



Weighted Root-Mean-Square (WRMS) Scatter of Baseline Length Estimates about Their Best-fit Straight Lines Plotted as a Function of Baseline Length. (Figure shows characteristic increase of WRMS scatter with increasing baseline length, indicating that length uncertainty is dominated by height of site errors.)

horizontal errors to be apparent in the figure. For short baselines, the height errors do not dominate the uncertainty in the baseline length. The standard deviation of the horizontal components inferred from the figure is < 10 mm. Both the horizontal and vertical scatterers are about 20 percent larger than would be expected given their respective statistical uncertainties. The additional scatter arises from a number of unmodeled effects in the analysis. The software is currently being upgraded to incorporate the effects of ocean-tide loading, the fluid core on the solid-earth tide, and the brightness distribution of the radio sources. Water-vapor radiometer data are also being examined to see if a parametric model for the effects of azimuthal asymmetry in the distribution of water vapor can be developed.

Advanced Gravity Field Modeling: A key contributor to accurate and detailed global gravity models was the satellite altimeter, which provided measurements of the sea surface height (geoid height) over most of the oceans. Although almost a decade old, the altimeter data are still being analyzed to improve and expand existing models. Extensive tests were conducted to compare surface ship data with gravity anomalies predicted from a combined Geos-3/Seasat altimeter data set. These tests led to routine procedures for the prediction of point gravity anomalies and sea surface heights. Approximately 2.2 million useful predictions were made of point values which were also formed into 0.5° x 0.5° and 1° x 1° mean values for comparison with terrestrial data. Various analyses were carried out with this data set, including the computation of spectra that show potential coefficient behavior at degrees up to about 900. From these analyses, we conclude that the gravity field on the ocean's surface is definitely smoother than on land areas.

The preferred representation for global gravity models is a spherical harmonic expansion. The reasons for this are largely computational since, with regularly gridded data, one can take advantage of the Fast Fourier Transform to analyze data along bands of constant latitude. Expansions to degree and order 250 (63001 coefficients) or even 360 (130321 coefficients) have been determined. The solution to degree 250 was obtained by first combining satellite-derived potential coefficients (NASA's GEM12) with a set of 1° x 1° mean free air anomalies. These anomalies were formed by merging a terrestrial set and the set derived from Geos-3/Seasat altimeter data. The combination solution included downward continuation corrections to the surface anomalies and ellipsoidal corrections to the a priori potential coefficients. The adjustment yielded 582 potential coefficients and 64800 1° x 1° anomalies. Two combination solutions were made, one that excluded geophysically predicted anomalies and one that included 5547 such anomalies. The potential coefficients were determined through an optimal estimation procedure where, primarily, sampling error was minimized. By comparing geoid undulations from these solutions with undulations at Doppler stations in North America, the root mean square difference was found to be 1.55 m.

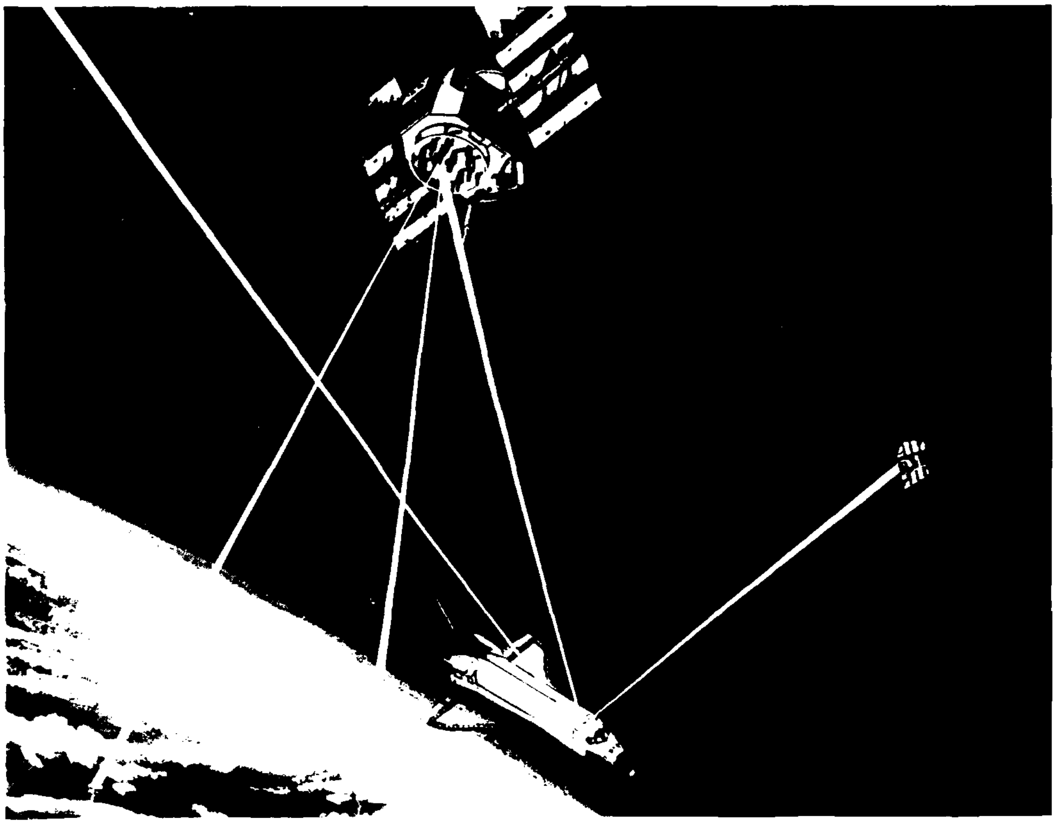
The computational efficiency of algorithms for generating high-degree spherical harmonic expansions is clearly demonstrated with these new models, but the loss of computational accuracy at the very high degrees is a problem requiring careful analysis. A method was developed that evaluates spherical harmonics, exactly at any degree, exclusively with integer operations. Thus, problems of accuracy and recursion stability are avoided and the algorithm depends only on the available computer time and memory capacity.

Local gravity estimation often depends on realistic models for crustal masses and the levels of isostatic compensation. The new, more detailed, and accurate gravity models, however, suggest a much deeper level of compensation than the 30 km of the generally accepted isostatic model of Airy and Heiskanen. To restore consistency with the gravity model requires a modification of the isostatic model. One proposal smoothes the root/antiroot interface of the Airy/Heiskanen model according to the Vening Meinesz system of regional compensation. An iterative least-squares process was designed that provided parameter estimates of an isostatic model in best possible agreement with the observed gravitational potential of the earth. Based on these parameters a set of harmonic coefficients of the topographic-isostatic potential, complete up to degree and order 180, was also computed.

An example of the significance of accurate topographic-isostatic models arises in the upward continuation of surface gravity data. The computation of the gravity vector in space is based on the solution to a boundary-value problem, where the boundary is a sphere and perturbations of the earth's surface from a sphere are treated separately using terrain data and density models.

Although gravity data for global gravity models exist for most parts of the globe, some regions, including the polar caps and inaccessible continental areas, are largely devoid of adequate gravity surveys. Observing the motion of a near-earth, polar-orbiting satellite fills the gaps, provided the observing stations are also globally distributed. The most practical set of such stations is the constellation of Global Positioning System satellites, which is designed to provide worldwide continuous positioning and navigation capabilities. The concept of satellite-to-satellite tracking is not new for global gravity surveying (see the figure) but the existence of GPS offers for the first time the capability to determine the total (three-dimensional) vector of gravity uniformly and consistently over the entire globe. The proposed low-orbit satellite is the shuttle (STS), whose continued support ensures the viability of the gravity mapping mission at relatively low cost. Also, the shuttle avionics already provide for a GPS receiver and antennas. Therefore, the only added instrumentation package would consist of accelerometers and inertial sensors to detect and record nongravitational accelerations which must be subtracted from the accelerations determined by GPS tracking. Anticipated accuracies are 1-2 mGal for each gravity vector component averaged over 100-200 km squares.

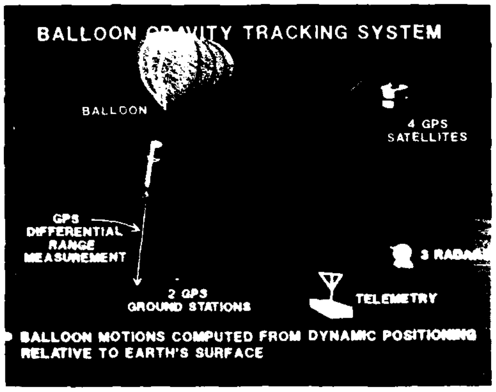
Balloonborne High-Altitude Gravimetry: Gravity field values at high altitudes (30 km) are normally estimated from upward continuation of surface measurements, or downward continuation of satellite measurements as computed from orbital perturbations. These techniques are well developed with generally accepted results but are subject to some limitations. Upward continuation depends upon the quality and distribution of surface data, usually nonuniformly spaced and taken from different surveys. Thus, gaps and uneven spatial distributions may result in inaccurate upward continued estimates. With increasing altitude, short wavelength information from crustal structure is attenuated and not recover-



Satellite-to-satellite tracking betw..en receiver on STS and GPS satellites will allow determination of earth's gravity field. (Non-inertial forces on STS will be measured by on-board accelerometer.)

able from downward continuation from satellite altitudes.

Verifying gravity databases and models requires establishing the validity of the models at locations where measurements have not been made. While such models can currently be effectively tested at ground level, their validation at altitude awaits the development of suitable approaches. The Air Force Geophysics Laboratory is developing a program to verify gravity-model estimates by directly measuring gravity using high-altitude balloons (see the figure). A gravimeter package suspended beneath a balloon is in a dynamic, and largely unpredictable, environment, sensing not only the earth's gravitational acceleration but also all accelerations due to the motions of the balloon system. For a specified time interval (1 sec) during which a measurement is made, the variation in balloon acceleration is expected to be significantly greater than the variation expected in the earth's field. Therefore, additional inertial instrumentation is required to measure as many balloon motions as possible, such as rotation, bobbing, and swaying. As all such ancillary sensors are dependent on the local inertial frame, gravitational accelera-



High-Altitude Gravity Differential GPS Measurements Used to Precisely Position Balloonborne Gravimeter.

tions cannot be separated from vertical balloon accelerations without additional data acquired independently of the frame of reference of the balloon. These independent data are extracted from external balloon tracking, which must accomplish three objectives: (1) measure the gravimeter package accelerations (especially the vertical) referred to a ground-based coordinate system, (2) measure velocity for estimation of the Eotvos effect, and (3) measure gravimeter position, which is used as an input to the gravity model. Combining balloon data with tracking data allows for the separation of balloon-induced accelerations from gravitational accelerations.

The long-term goal is to determine gravitational acceleration at altitudes ranging from near ground level to about 30 km, to an accuracy of 1 mGal (~1 ppm). To achieve this goal, kinematic motions of the sensors must be measured to better than 1 mGal vertical acceleration, horizontal velocity to 5 cm/sec, and altitude to 3 meters. The quality of data for the on-board inertial sensors and external tracking are crucial to the success of the experiment.

To date, we have two successful flights. The first was a feasibility test of the sensors and experimental methods. Results from the first flight, closure to within 27 mGal, demonstrated that external tracking (ground-based radar) was inadequate for the job, and the best hope to resolve this problem lay in using differential GPS tracking. The second flight focused on GPS differential tracking and included improved inertial instrumentation. Current results are very encouraging. Although the analysis is not yet complete, we have closure between measured and modeled gravitational acceleration to 0 ±20 mGal without any elaborate combined processing of inertial and GPS data. The combined processing system is being tested now, and should reduce the uncertainty to ±5 mGal with current data.

If our expectations are realized, we will plan a third flight to resolve the problems found in both flights, and expect to measure to an uncertainty of ±1 mGal or better. The third flight must necessarily wait until the GPS constellation is expanded, probably not until 1991 or 1992.

Gravity Gradiometer: All Air Force inertial navigation systems (INS) rely on a model of the earth's gravity field for precise point-to-point navigation. While satellite-based measurements provide long wavelength information about the earth's gravity field, only near-earth measurements can accurately determine the short wave-length features. Until now, the collection of these types of data has been labor-intensive and slow. In fact, in geographically harsh areas, conventional gravity-survey methods are nearly impossible to implement and suffer from lack of geodetic control and, therefore, accuracy. As the accuracy of INS has increased, so has the demand for large amounts of short wavelength gravity data. This demand accelerated the search for an automated mobile gravity-data acquisition system.

AFGL has explored the possibility of measuring gravity from moving platforms, such as aircraft, since the 1950's. Early results indicated that using standard gravimeters would present great difficulties in separating the acceleration due to gravity from other accelerations induced by aircraft motion. In the early 1960's, a new concept arose that called for measurements of gravity gradients rather than gravity. The measurement of gravity gradients is more suited to moving environments for several reasons. First, it resolves the problem of the fundamental inseparability of inertial and gravitational accelerations that has hampered moving-base measurements and gravity. From the relationship between accelerations in inertial and noninertial reference frames, it is easy to show that an inertially stabilized gradient-measuring system yields data that are independent of linear inertial accelerations. Second, a gradiometer system comprises three (differently oriented) gradient sensors, sufficient for the determination of the five independent elements of the gravity gradient tensor. This permits the direct calculation of not only the vertical gravity component, but also the deflection of the vertical (DOV); i.e., the full gravity vector is obtained. Third, because the gradiometer is an instrument designed to sense the short-wavelength variations of earth's gravity field in the form of gradients, it provides the type of data necessary for accurate interpolation of gravity between survey tracks.

Full-scale development of a land and airborne Gravity Gradiometer Survey System (GGSS) is now underway. GGSS instrumentation has been installed in a specially prepared motor van. Gravity gradients can be measured from the van by driving through the area of interest. For gravity surveys covering larger areas the van is loaded onto a C-130 cargo aircraft, where it is operated in an airborne mode (see the figure). The C-130, equipped with power conditioning equipment and a special interface to the autopilot, flies a predetermined survey pattern controlled by the GGSS computer. Navigation data from the Global Positioning System (GPS) are used by the GGSS for real-time aircraft tracking and control. The on-board computer calculates heading and altitude corrections based on GPS data plus aircraft attitude information from a gyro-stabilized platform. Track corrections processed by the GGSS computer are sent to the autopilot which controls the aircraft.

A critical aspect of an airborne gradiometry system is that the data coverage over the survey area must be sufficiently dense. The expected estimation accuracies for an ideal survey at 600 m altitude and 5 km track spacing is 1 mGal in magnitude and 0.2 arcsec for deflections over a large area. Tracks are assumed to run in two orthogonal directions. The error of estimation is quite sensitive to track spacing, however, and the accuracy goal cannot be achieved with unidirectional tracks.

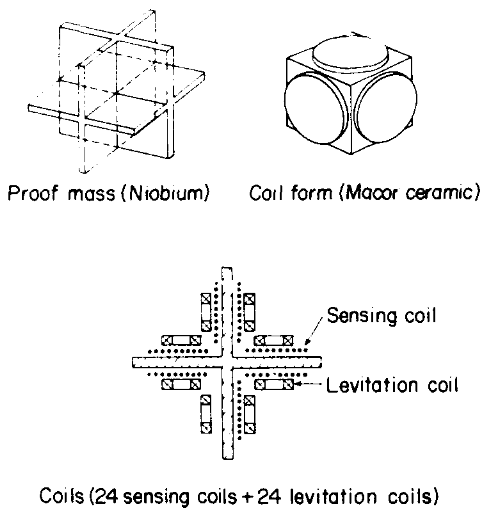
The test program will take place in mid 1987. It will be divided into two parts: land and airborne. The land test will evaluate the GGSS repeatability and its ability to transfer both gravity and DOV between known astro-geodetic stations. The airborne test will assess how well the gradiometer can reproduce very accurate

Loading the Gravity Gradiometer Survey System Van onto a C-130 Aircraft to Conduct an Airborne Survey.

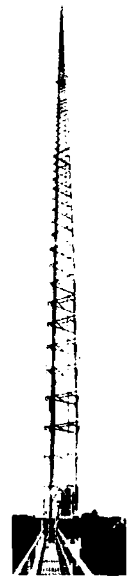
ground truth data over a large area (300 km by 300 km).

Superconducting Accelerometer: AFGL is sponsoring a program to build a superconducting accelerometer to achieve several orders of magnitude improvement in the accuracy of linear and angular acceleration measurements. The instrument being developed will use a magnetically levitated "inverse cube" as the proofmass. Each of the 24 faces of the inverse cube contains a magnetic-field "sensing" coil and a magnetic-field "producing" coil, for a total of 48 coils (see the figure). Movement of the proofmass is reflected by an increase (or decrease) in the current in the sensing current loops. By changing the current through a combination of "producing" current loops, the magnetic "pressure" exerted on any one of the 24 faces of the proofmass can be increased (or decreased) producing a feedback mechanism to recenter the proofmass between the 24 coils. This feedback scheme allows the proofmass to be stabilized along the three rotational and three translational axes.

Two properties of superconducting material are being utilized in the feedback mechanism used as the basis for the construction of this accelerometer: the Meissner effect and the zero electrical resistance of superconducting materials. The Meissner effect excludes magnetic fields from passing through the surface of a superconducting material, permitting the proofmass to be floated with magnetic fields. The second effect allows an electric current to circulate through a superconducting electric current loop without energy dissipation, thus keeping the magnetic proofmass absolutely stable.



Schematic Diagram of 6-Axis Cryogenic Accelerometer Proof Mass with Sensing and Levitation Coils.



TV Tower (2,000 ft) from which AFGL scientists will measure gravity at various levels to test "fifth force" hypothesis.

Under a Forecast 2 initiative, possible applications of this cryogenic instrument to inertial navigation systems will be studied. It may be possible to build a much more accurate and compact inertial navigation system for aircraft or cruise missiles that can operate without prior knowledge of the gravitational field. Superconducting technology may also allow the construction of more accurate gravimeters, seismometers, and gravity gradiometers.

"Fifth Force" Studies: AFGL scientists are searching for the existence of a non-Newtonian "Fifth Force" - an additional fundamental force beyond electromagnetism, gravity and the strong and weak interactions of physics. If such a force is found to exist, it may be the link between quantum mechanics and general relativity, thus aiding in the search for a unified field theory. This extremely weak repulsive force is postulated to act between objects separated by distances of less than several hundred meters. Over the last decade, there is growing evidence that the measured value of G from borehole measurements is about 0.8 percent higher than the commonly accepted value. The leading hypothesis, assuming the measurements are correct, is that G is a function of distance. To test this hypothesis, the Geodesy and Gravity Branch will measure gravity as a function of altitude along a 2,000 foot television tower (see the figure). Additional ground measurements tied to an absolute gravity station, including measurements of topographic elevations and the vibration spectra of the tower, will contribute to providing the appropriate accuracy. Also in the planning stage are underground gravity measurements in a deep drill hole in the Greenland ice cap. AFGL is also supporting new Eotvos and differential Galilean experiments.

GEOKINETICS

The ever-increasing technical sophistication of Air Force systems has made optimum operational performance susceptible to earth motion (geokinetic) environments. Some areas of recent concern include inertial guidance instrumentation, missile payload integrity, and advanced missile basing-mode vulnerability. Unfortunately, performance enhancement increases sensitivity to geokinetic effects, and therefore the potential for error, caused by the local geokinetic environment, is expanded.

Associated structures and containment areas may also be susceptible to the geokinetic environment. The response of these structures to disrupting strong motional forces must be established and compensation made within the adverse frequency bands to preserve the integrity of these facilities and the integrity of Air Force operations.

The geokinetic environment also impacts upon optimum Air Force system capabilities and performance in the following areas: (1) seismic discrimination: for determining distinguishing source characteristics generated by earthquakes and explosions, or vehicular and aircraft activity whose seismic and acoustic signatures are masked or colored by transmission path and environmental noise factors; (2) seismic communication: for preserving the intelligence portion of the generated ground signal that is predicated on the intensity of the local earth background-noise environment and ground transmission path; (3) seismic detection: for monitoring covert activities and maintaining physical security; and (4) environmental impact statements: for establishing database criteria for engineering and juridical concerns.

To suppress, or compensate for, geokinetic effects, the attributes of the ground transmission path must be known. Since these characteristic attributes depend on the local geology, the transmission properties of the source-receiver environment must be fully assessed. The objectives, then, of the geokinetic research and development conducted by the Earth Sciences Division are threefold: (1) to develop methods for rapidly assessing the environmental seismic propagation attributes of a local site, (2) to forecast and verify site ground-motion responses, and (3) to recommend methods for suppressing and compensating for these motions.

Seismology: Geology, tectonics, and seismology are studies to predict the spatial and temporal properties of motions of the earth's crust over a wide range of frequencies. Specific efforts include measurement and interpretation of long-period secular deformation and realistic modeling of the effects of seismic motion on Air Force systems and structures.

The Solid Earth Geophysics Branch conducts a research program aimed at predicting the level, frequency content, and duration of seismic ground motions caused by earthquakes and explosions. Previous work has shown that complex geology at a facility affects seismic wave propagation and surficial ground motion. These effects cannot be adequately represented using simple assumptions such as plane layering, since the effects include complications such as diffraction, scattering, and wave mode conversion. Theoretical modeling includes such techniques as three-dimensional ray tracing, finite element, boundary integral equation, and

Kirchhoff methods, as well as standard mode and ray theory computations.

Field studies have focused on providing data to test the theoretical calculations as well as measurements of earth properties. A seismogram written at an AFGL station 53 km from the MINOR SCALE high-explosive test (4800 ton nuclear simulation test performed at White Sands Missile Range in July, 1985, under DNA sponsorship) shows nearly 1 minute of high amplitude signals. The recorder was situated in the Tularosa Basin, a deep sediment-filled valley. Analysis of this record shows that the wave packets are surface waves multipathing, causing reverberations in the valley. White Sands is a test and possible deployment location for the mobile ICBM system.

A joint effort by AFGL, the U.S. Geological Survey, the Air Force Weapons Laboratory, and a university consortium to measure crustal properties in the Basin and Range geological province of western Nevada was undertaken in July, 1986. This part of the western United States is undergoing crustal extension caused by tectonic forces beneath the continent. Anomalous crustal structure and frequent earthquakes result. Because of its low population, the area is being considered for advanced ICBM basing. The AFGL part of this experiment focused on obtaining seismic data within and across topographic features. Of particular interest is how energy from an explosion in one valley couples to another valley. Analysis is just beginning on the more than 15,000 seismograms obtained during this two-week experiment.

A number of smaller seismic experiments were also conducted during the reporting period. Measurements of how acoustic waves from small aerial explosions suspended from tethered balloons couple to seismic energy were acquired at Fort Devens, Massachusetts in May, 1986. AFGL and AFWL scientists recorded acoustic and seismic signals in a variety of topographic and vegetation conditions. An array of borehole tiltmeters has also been installed at Yellowstone National Park, Wyoming, in a program to detect tidal admittance anomalies caused by the volcanic caldera and to search for possible earthquake precursors. Also, a pair of tiltmeters has been emplaced in 50 m boreholes in the La Malbaie seismic region near Charlevoix, Quebec, to detect the theoretically predicted changes in the local response to earth tides as rocks are stressed toward their fracture strengths.

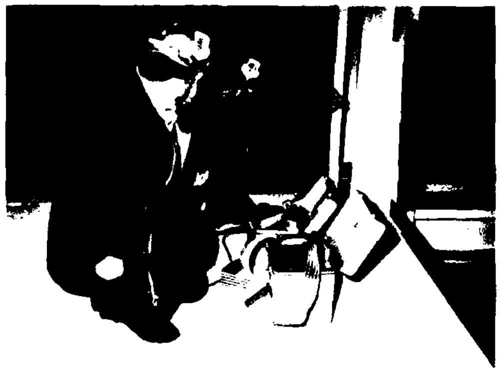
In a cooperative program with the U.S. Geological Survey, NASA, and a number of universities, AFGL operated a biaxial tiltmeter at the University of California Pinon Flat Geophysical Observatory near the San Andreas fault zone northeast of San Diego. The responses of diverse instruments, including tilt, strain and stress meters, and seismometers operating in an active tectonic area, are being compared.

Seismo-Acoustic Studies: During 1985 and 1986, AFGL continued to provide support to the Space Division Space Transportation System (STS) Program. The primary efforts were directed towards satisfying requirements to ensure the structural integrity of major ground-support facilities at V23, the Vandenberg AFB Shuttle launch facility. This support was divided into two elements: the completion of launch-induced vibro-acoustic environment forecasts for the site and the design and installation of a Vibro-Acoustic Measurement System (VAMS) at V23.

During the period 1982 through 1984, AFGL had conducted a series of studies at Kennedy Space Center to determine an acoustic source model for the shuttle launch and an explosives sounding program at V23 to determine the site-specific responses of major structures to acoustic loading. These efforts culminated in 1985 with the completion of the AFGL forecasts for the launch-induced vibro-acoustic environment at V23. The major conclusions of this study were: (1) a high probability exists that the Payload Preparation Room (PPR) and the Payload Changeout Room (PCR) will pound during an STS launch; (2) motion levels in certain locations within the Administration Building approach levels of concern for the survivability of sensitive equipment; (3) the pressure loads observed at the site, possibly including the loads reflected back onto the shuttle, itself, could be as such as 15 dB higher than those experienced at Kennedy; (4) if pounding does not occur between the PPR and the PCR, the motion levels within the PPR should be within specification. It was also noted that these studies indicated that the seismic hazard for the facility may have been underestimated, especially when all the mobile structures at the site are moved over the launch mount.

In late 1985, AFGL began the installation of the VAMS at V23 (see the figure). This system was designed by AFGL to monitor the vibro-acoustic launch environment during the first three shuttle launches from Vandenberg AFB. However, installation of this system was halted following the Challenger explosion in January, 1986. During this hiatus, AFGL has continued to improve and upgrade the VAMS design.

The VAMS is an easily reconfigurable, flexible, distributed computer network designed for monitoring environmental motions. The heart of the system is a master control unit, a super fast microprocessor



AFGL Scientists Measuring the Vibro-acoustic Environment at the V23 Space Shuttle Launch Facility, Vandenberg AFB.

to centrally manage the network and peripheral processors, as well as to continually record data. Closely coupled to the master is a standard microcomputer for serial code execution, and an array processor for the massively parallel data processing required in digital signal processing. Five front-end slave units are coupled to the master.

Currently, the VAMS is capable of recording and analyzing 80 channels of seismic and/or pressure signals with a maximum frequency of interest at 50Hz. Accuracy is better than 0.5 percent for pressure in the range from 0 to 5 psid and 0 to 20 psia. Sensitivity of the seismometers to motion is better than 2×10^{-6} cm/sec. This is well below the average ground noise present.

During the period August, 1985, to July, 1986, AFGL maintained a strong ground-motion recording station at V23. This support was requested by the Shuttle Activation Task Force to satisfy NASA-imposed requirements. This system was set up to automatically record any seismic event with ground accelerations exceeding 0.01 g at V23. During the year that the system was operational, no events exceeding this level were detected.

During 1985 and 1986 Ballistic Missile Office objectives were supported by theoretical studies for the MX Deep Basing Mode. A seismic ray-tracing code developed for AFGL was used to study the seismic motions that could impact missile operations for silos located within mountains. The major effort has been the detection of surface cratering by seismic means. It has been shown that operational deep-based crews could detect the location of surface craters by using small explosive detonations to image the ground surface.

In 1984, Logistics Command requested that AFGL examine the vibration problems associated with the acoustic emissions of jet engine ground run-up test facilities (Hush Houses). This effort has continued in 1985 and 1986 with analysis of data taken at Luke AFB in late 1984. AFGL has been able to identify the location of an equivalent monopole acoustic source directly over the Hush House exhaust deflector. This is a major accomplishment in establishing a pre-construction forecast technique for estimation of vibro-acoustic environment degradation in nearby structures due to Hush House operations. In October, 1986, additional field studies were completed at Ft. Smith, Arkansas, relating to this problem. Preliminary data reduction was begun on these data in 1986.

As an In-House sponsored project, the Solid Earth Geophysics Branch initiated a study for the detection and tracking of low-flying aircraft using seismo-acoustic means (see the figure). The goal of this research is to provide a passive means for the detection and tracking of aircraft and cruise missiles that, for various reasons,

Monitoring the Seismic-acoustic Environment Generated by Overflights of Low-Level Aircraft. (Measurements are used to develop alternative methods to radar for the detection and tracking of low observable aircraft.)

might be difficult to detect using conventional methods such as radar. During 1986 a field effort was conducted to establish a data base for this study. A field site was selected under the SAC Low Level Training Route at La Junta, Colorado. During October 1986, seismic and acoustic data were collected at the site to establish ambient noise conditions in preparation for the full field effort.

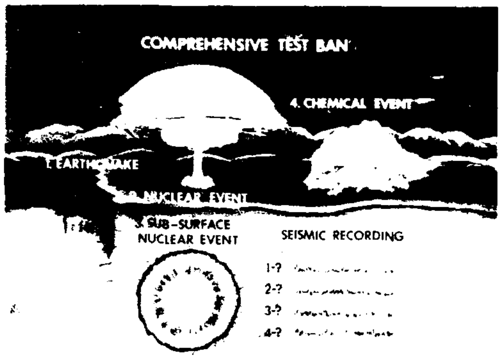
AFGL has also begun a study of the seismo-acoustic environment generated by a Peacekeeper missile launch. A seismic and acoustic array was deployed at the Vandenberg AFB Peacekeeper launch test facility late in 1986 to record the environment during a series of launches to be made from that site in 1987.

Studies were also conducted with the goal of increasing the accuracy of large earthquake-motion forecasts for specific sites by improved analysis techniques. Topics being studied include improving the estimation quality of static to dynamic elastic-moduli variations and the use of small earthquake motions to determine Green's functions for larger events. This study was completed in 1986.

Comprehensive Test Ban Verification: The Air Force is responsible for providing information for the verification of treaties dealing with the detonation of underground nuclear explosions. The primary treaties in effect are the Limited Threshold Test Ban Treaty (TTBT), negotiated with the Soviet Union in 1974, and the Peaceful Nuclear Explosion Treaty (PNET), signed in 1976. While the TTBT has never been ratified, the signatory countries contend to abide by the 150 kiloton upper limit imposed for the yield of nuclear devices.

Resources for monitoring these treaties are seismic networks, surveillance satellites, sampling of radioactive debris and, potentially, on-site inspection and measurements. The Department of Defense conducts research in all these areas. Currently, seismological techniques are the primary means of detecting, discriminating, and determining the locations and yields of nuclear tests.

In support of the Air Force mission to verify treaties, the Solid Earth Geophysics Branch manages the Defense Advanced Research Projects Agency (DARPA) Program in Nuclear Test Ban Verification Basic Research. One of DARPA's charters is to provide scientific support to the arms control activities of the government. This charter complements the operational mission of the Air Force to verify compliance with existing arms control treaties. Any verification technique used by the Air Force or discussed by statesmen in the course of treaty negotiations must be based on well-understood and demonstrable physical principles. DARPA has, for the past 25 years, supported a program in basic research to improve existing seismic verification techniques and develop new ones. AFGL management of the DARPA program allows for coordination of program objectives with Air Force requirements, and integration of basic research results into Air Force operations.



Seismic Waves Generated by Sources Contributing to Detection Ambiguities for Differentiating Nuclear Events from Other Seismic Sources. (These ambiguities are the primary complicating factors in Test Ban Treaty negotiations.)

In general, deciding if a seismic event were generated by a nuclear explosion consists of three distinct problems: detection, discrimination, and yield determination (see the figure). The detection problem is simply detecting that an event has been recorded. This can be made difficult because of seismic noise generated by cultural and natural sources such as roadway traffic and weather fronts. Discrimination of the event involves deciding if it is an earthquake, chemical blast, or nuclear explosion. This aspect of the problem can be difficult because a chemical explosion detonated in a rock quarry, for example, can look very similar to a local earthquake and may even resemble a small nuclear explosion. Determination of the yield of a nuclear event is the last step; it is a function of seismic wave amplitude. This portion of the overall problem is not straightforward because the amplitudes of the seismic waves generated at one test site may differ substantially from those at another test site. Therefore, it is not always possible to use yield/magnitude relations interchangeably from one test site to another.

The technical basis for monitoring underground nuclear explosions has not changed significantly in the past few years. However, as a result of the research performed in the AFGL/DARPA program, a more complete understanding of the physics of seismic sources, the effects of path variations on seismic wave propagation, and anomalous shear-wave generation by underground nuclear explosions has been made possible.

The focus of research performed to date has been to improve the capabilities of the United States to monitor underground explosions from long ranges (teleseismically). Teleseismic ranges are generally defined as greater than 2000 km. As a result of the Comprehensive Test Ban Treaty (CTBT) talks of 1977-1980, an agreement in principle exists to establish seismic stations in the Soviet Union. Because of this agreement, program research objectives have shifted toward developing methods to monitor a CTBT at regional distances (less than 2000 km). While signals recorded at these shorter distances are extremely complicated, they can, probably, be used to detect explosions of very small magnitude. In a CTBT scenario, detonations of all nuclear devices will be prohibited and presumably seismic stations will be placed at regional distances from test sites. Therefore, the verification problem reduces to that of identification and discrimination at regional distances from a suspected event.

The focus of the AFGL/DARPA program is now being redirected to regional seismology in an effort to develop techniques for analyzing shorter period data and developing regional discrimination methods.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

BATTIS, J.C.
STS Launch-Induced Vibration Forecasts for Vandenberg AFB
Proc. Shuttle Environment and Operations II Conf. (13-15 November 1985)

BATTIS, J.C. (AFGL); and CROWLEY, F.A. (Boston Coll., Newton, MA)
Forecasting Hush House Induced Vibro-Acoustics
Proc. Aircraft Noise in Modern Soc. Conf. (23-26 September 1986)

CROWLEY, F.A., (Boston Coll., Newton, MA) and OSSING, H.A. (AFGL)
Acoustic Forecast for Shuttle Launches at Vandenberg AFB
Proc. Shuttle Environment and Operations II Conf. (13-15 November 1985)

ECKHARDT, D.H.
Comment on the "Reanalysis of the Eötvös Experiment"
Phys. Rev. Lett. 57 (1 December 1986)
Isomorphic Geodetic and Electrical Networks: An Application to the Analysis of Airborne Gravity Gradiometer Survey Data
Geophysics 51 (November 1986)

JEKELI, C.
On Optimal Estimation of Gravity from Gravity Gradients at Aircraft Altitude
Rev. of Geophys. 23 (August 1985)
Gravity Vector Estimation from a Large Densely Spaced Heterogeneous Gradient Data Set Using Closed-Form Kernel Approximations
Proc. Third Internat. Symp. on Inertial Tech. for Surveying and Geodesy (January 1986)
Estimation of Gravity Disturbance Differences from a Large and Densely Spaced Heterogeneous Gradient Data Set Using an Integral Formula
Manuscripta Geodaetica 11 (1986)

JEKELI, C. (AFGL); WHITE, J.V., and GOLDSTEIN, J.D. (Analytic Sciences Corp., Reading, MA)
A Review of Data Processing in Gravity Gradiometry
Proc. Third Internat. Symp. on Inertial Tech. for Surveying and Geodesy (January 1986)

LAZAREWICZ, A.R.
Balloon Borne, High-Altitude Gravimetry
Adv. Space Res. 5 (1985)

LEWKOWICZ, J.F.
Tilt Observations from Shallow and Deep Borehole Arrays
Phys. of the Earth and Planetary Interiors 41 (1985)

MCCAFFREY, R.
On the Tectonic Significance of the "Delayed Aftershock" Sequence Associated with the 1977 Sumba Earthquake
Bull. of the Seismological Soc. of Am. (1986)

MICHEL, H.E., Capt.
The AF Geophysics Laboratory Vibro-Acoustic Measurement System (VAMS)
Proc. AIAA Shuttle Environment and Operations II Conf. (13-15 November 1985)

OSSING, H.A.
STS Vibro-Acoustic Environment at OASPL Maxima
Proc. AIAA Shuttle Environment and Operations II Conf. (13-15 November 1985)

PRESENTATIONS AT MEETINGS JANUARY, 1985 - DECEMBER, 1986

CIPAR, J. (AFGL); KADINSKY-CADE, K. (Massachusetts Inst. of Tech., Cambridge, MA); and EBEL, J.E. (Boston Coll., Newton, MA)
Crustal Thickness Measurements in Maine Using Observations of PmP
AGU Mtg., Baltimore, MD (19-23 May 1986)

CIPAR, J., KADINSKY-CADE, K., and JOHNSTON, J.C.
P and S Wave Structure of the White Mountains, Maine - New Hampshire
AGU Mtg., Baltimore, MD (27-31 May 1985)

ECKHARDT, D.H.
Status of the Gravity Gradiometer Survey Systems
12th Mtg. of the Internat. Gravity Comm., Toulouse, France (22-26 September 1986)
Status Update of the Gravity Gradiometer Survey System
AGU Mtg., San Francisco, CA (8-12 December 1986)

FUNDAK, T.J., Lt.
The Components of the Gravity Gradiometer Survey System: Integration and Testing
Third Internat. Symp. on Inertial Tech. for Surveying and Geodesy, Banff, Alberta, Canada (16-20 September 1985)

GOLDSBOROUGH, R.G., and FUNDAK, T.J.
The Gravity Gradiometer Survey System
Third Internat. Symp. on Inertial Tech. for Surveying and Geodesy, Banff, Alberta, Canada (16-20 September 1985)

JEKELI, C.
Gradiometry and Geodesy, or Separating Inseparables
14th Gravity Gradiometer Conf., Colorado Springs, CO (11-12 February 1986)

JEKELI, C., and LAZAREWICZ, A.R.
An Experiment to Test Newton's Law of Gravitation at a Scale of Several Hundred Meters
AGU Mtg., San Francisco, CA (8-12 December 1986)

JOHNSTON, J.C., and CIPAR, J.J.
Simulation of Ground Motion from Large Earthquakes
Internat. Assoc. of Seismology and Physics of the Earth's Interior Conf., Tokyo, Japan (22-26 August 1985)

JOHNSTON, J.C. (AFGL); and KERCHOFF, S. (Boston Univ., Boston, MA)
Results of a Small Digital Seismic Array Recording of a Large Ground Explosion in WSMR, NM, on 27 June 1985
AGU Mtg., Baltimore, MD (19-23 May 1986)

LAZAREWICZ, A.R.
High Altitude Gravity Measurements from, and Differential GPS Tracking of, Balloon-Borne Platforms
AGU Mtg., San Francisco, CA (8-12 December 1986)

LEWKOWICZ, J.F.
Borehole Geophysical Investigations to Identify Potential High Level Nuclear Waste Repository Sites in the Palo Duro Basin of Texas
AGU Mtg., San Francisco, CA (9-13 December 1985)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

BATTIS, J.C.
Vibro-Acoustic Forecasts for STS Launches at V23, Vandenberg AFB: Results Summary and the Payload Preparation Room
AFGL-TR-85-0133 (8 May 1985), ADA162192

ILIFF, R.L., and SANDS, R.W., MSgt.
The AFGL Absolute Gravity System's Error Budget Revisited
AFGL-TR-85-0102 (8 May 1985), ADA162230

JOHNSTON, J.C.
Simulating a Large Wasatch Front, Utah, Earthquake Using Small Earthquake Recordings as a Green's Function
AFGL-TR-86-0120 (28 May 1986), ADA175203

LAZAREWICZ, A.R., SCHILINSKI, B.J., COWIE, R.J., RICE, C.L. (AFGL); MOSS, P. and CARTER, L.N. (Bedford Research Assoc., Bedford, MA)
Balloon-Borne, High-Altitude Gravimetry
AFGL-TR-85-0342 (31 December 1985), ADA169942

POHLIG, K.O., 1Lt., and KIRCHOFF, S.
Design of the AFGL Prototype Long Baseline Tiltmeter
AFGL-TR-85-0196 (29 August 1985), ADA169132

CONTRACTOR PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

ABBOT, R.I., BOCK, Y., COUNSELMAN, C.C., KING, R.W., GOUREVITCH, S.A., and ROSEN, B.J. (Massachusetts Inst. of Tech., Cambridge, MA)
Interferometric Determination of GPS Satellite Orbits
Proc. 1st Internat. Symp. on Precise Positioning with the Global Positioning System (15-19 April 1985)

BOCK, Y., ABBOT, R.I., COUNSELMAN, C.C., GOUREVITCH, S.A., and KING, R.W. (Massachusetts Inst. of Tech., Cambridge, MA)
Establishment of Three-Dimensional Geodetic Control by Interferometry with the Global Positioning System
J. Geophys. Res. 90 (10 August 1985)

BOCK, Y., ABBOT, R.I., COUNSELMAN, C.C., KING, R.W., and GOUREVITCH, S.A. (Massachusetts Inst. of Tech., Cambridge, MA)
Three Dimensional Geodetic Control by Interferometry with GPS: Processing of GPS Phase Observables
Proc. 1st Internat. Symp. on Precise Positioning with the Global Positioning System (15-19 April 1985)

MORGAN, P.J., KING, R.W., and SHAPIRO, I.I. (Massachusetts Inst. of Tech., Cambridge, MA)
Length of Day and Atmospheric Angular Momentum: A Comparison for 1981-1983
J. of Geophys. Res. 90 (10 December 1985)

VIDALE, J., HELMBERGER, D., and CLAYTON, R. (California Inst. of Tech., Pasadena, CA)
Finite-Difference Seismograms for SH Waves
Bull. Seismological Soc. of Am. 75 (December 1985)

CONTRACTOR PRESENTATIONS JANUARY, 1985 - DECEMBER, 1986

MERENYI, R.C., BRZEZOWSKI, S.J., and HELLER, W.G. (Analytic Sciences Corp., Reading, MA)
Radio Interferometry in a Moving-Base Application
First Internat. Symp. on Precise Positioning with the Global Positioning System, Rockville, MD (15-19 April 1985)

CONTRACTOR TECHNICAL REPORTS JANUARY, 1985 - DECEMBER, 1986

APSEL, R.J., MELLMAN, G.R., and WONG, P.C. (Sierra Geophysics, Inc., Redmond, WA)
Three-Dimensional Wave Propagation Using Boundary Integral Equation Techniques
AFGL-TR-85-0245 (September 1985), ADA164498

BACHE, T.C., and BRATT, S.R. (Science Applications International Corp., San Diego, CA)
High Frequency P Wave Attenuation and Degradation of Detection Capability by Large Earthquakes
AFGL-TR-85-0211 (5 September 1985), ADA164733

BAKER, T.F., EDGE, R.J., and JEFFRIES, G. (Bidston Obs., Birkenhead. UK)
High Precision Tidal Gravity
AFGL-TR-85-0203 (20 June 1985), ADA160676

BARKER, J.S., BURDICK, L.J., and WALLACE, T.C. (Woodward-Clyde Consultants, Pasadena, CA)
Analysis of Near-Field Seismic Waveforms from Underground Nuclear Explosions
AFGL-TR-85-0321 (15 September 1985), ADA165227

BARKER, J.S., BURGER, R.W., BURDICK, L.J., and LAY, T. (Woodward-Clyde Consultants, Pasadena, CA)
Inversion for Source Parameters of Underground Nuclear Explosions with Implications for Yield Estimation
AFGL-TR-86-0142 (15 March 1986), ADA174003

BLAHA, G. (Nova Univ. Oceanographic Ctr., Dania, FL)
Detailed Spherical-Harmonic Representation of the Earth's Gravity Field and Tidal Effects from Altimetric Adjustments
AFGL-TR-85-0076 (February 1985), ADA160419

BRZEZOWSKI, S.J. (Analytic Sciences Corp., Reading, MA)
Gravity Gradiometer Survey Errors
AFGL-TR-85-0066 (March 1985), ADA165575

BRZEZOWSKI, S.J., and MERENYI, R.C. (The Analytic Sciences Corp., Reading, MA)
Aided-Airborne Gravity Gradiometer Survey System (GGSS) Study: Final Report
AFGL-TR-86-0059 (March 1986), ADA170749

CENTER, C.J. (Boston Coll., Newton, MA)
System Level Programming of the Preston Scientific Analog to Digital Converter on the LSI-11/23 Bus
AFGL-TR-86-0205 (29 August 1986), ADA175511

CHAO, D., and BAKER, E.M. (The Ohio St. Univ., Columbus, OH)
A Study of the Optimization Problem for Calibrating a Lacoste and Romberg "G" Gravity Meter to Determine Circular Errors
AFGL-TR-85-0208 (September 1985), ADA165218

CLAYTON, R.W., HARKRIDER, D.G., and HELMBERGER, D.V. (California Inst. of Tech., Pasadena, CA)
Body and Surface Wave Modeling of Observed Seismic Events
AFGL-TR-86-0021 (22 January 1986), ADA169413

CORMIER, V.F. (Massachusetts Inst. of Tech., Cambridge, MA)
Teleseismic Waveform Modeling Incorporating the Effects of Known Three-Dimensional Structure Beneath the Nevada Test Site
AFGL-TR-85-0264 (I) (22 October 1985), ADA166443
Teleseismic Waveform Modeling Incorporating the Effects of Known Three-Dimensional Structure Beneath the Nevada Test Site
AFGL-TR-86-0081 (II) (14 April 1986), ADA169965

CROWLEY, F.A. (Boston Coll., Newton, MA)
Acoustic Forecast for Shuttle Launches at Vandenberg AFB
AFGL-TR-85-0335 (13 November 1985), ADA162862

CRUZ, J.Y. (The Ohio St. Univ., Columbus, OH)
Disturbance Vector in Space from Surface Gravity Anomalies Using Complementary Models
AFGL-TR-85-0209 (August 1985), ADA166730
Ellipsoidal Corrections to Potential Coefficients Obtained from Gravity Anomaly Data on the Ellipsoid
AFGL-TR-86-0178 (August 1986), ADA176901

CURRIE, D.G., and WELLNITZ, D.D. (Univ. of Maryland, College Park, MD)
On Two Color and CCD Methods for the Determination of Astronomic Position
AFGL-TR-86-0111 (14 March 1986), ADA174088

DAINTY, A.M. (Georgia Tech. Research Inst., Atlanta, GA)
Coda Observed at NORSAR and NORESS
AFGL-TR-85-0199 (20 August 1985), ADA166454

DAINTY, A.M. and TOKSOZ, M.N. (Massachusetts Inst. of Tech., Cambridge, MA)
Influence of Scattering on Seismic Waves
AFGL-TR-86-0218 (21 October 1986), ADA179175

DAVIS, J.L. (Harvard Coll., Obs., Cambridge, MA)
Atmospheric Propagation Effects on Radio Interferometry
AFGL-TR-86-0243 (April 1986), ADA178405

DEBRA, D., and BREAKWELL, J. (Stanford Univ., Stanford, CA)
Study to Develop Use of Gravity Gradiometers in Gravity Mapping
AFGL-TR-86-0166 (February 1986), ADA179611

ECKHARDT, R.J. (OPHIR Corp., Lakewood, CO)
A Sensitivity Study of a One-Dimensional Time-Dependent Warm Cumulus Cloud Model
AFGL-TR-85-0331 (September 1985), ADA170141

ELGIN, J.B., and DUFF, J.W. (Spectral Sciences, Inc., Burlington, MA)
A Monte Carlo Description of the Sampling of Stratospheric Ion Clusters Via a Mass Spectrometer
AFGL-TR-85-0319 (October 1985), ADA168523

FABIAN, W. (Analog Modules, Inc., Longwood, FL)
Very Short Baseline Measurement System
AFGL-TR-85-0081 (1 March 1985), ADA169258

FREEDEN, W. (The Ohio St. Univ., Columbus, OH)
Computation of Spherical Harmonics and Approximation by Spherical Harmonic Expansions
AFGL-TR-85-0063 (February 1985), ADA160445

HELLER, W.G., and SHIPP, R.F. (Analytic Sciences, Corp., Reading, MA)
Airborne Gravity Gradiometer Survey System Aided by a High-Accuracy Master Inertial Navigation System
AFGL-TR-85-0119 (11 May 1984), ADA155525

HELMBERGER, D.V., HARKRIDER, D.G., and CLAYTON, R.W. (California Inst. of Tech., Pasadena, CA)
Interaction of Seismic Waves with Complex Structures
AFGL-TR-85-0139 (21 May 1985), ADA166715

HERMANN, R.B. (St. Louis Univ., St. Louis, MO)
Lg Wave Excitation and Propagation in Presence of One-, Two-, and Three- Dimensional Heterogeneities
AFGL-TR-86-0025 (I) (27 January 86), ADA169004
Lg Wave Excitation and Propagation in Presence of One-, Two-, and Three- Dimensional Heterogeneities
AFGL-TR-86-0026 (II) (1 February 1986), ADA169325

ISAACS, R.G., WANG, W.-C., WORSHAM, R.D., and GOLDENBERG, S. (Atmospheric and Environmental Research, Inc., Cambridge, MA)
Multiple Scattering Treatment for Use in the LOWTRAN and FASCODE Models
AFGL-TR-86-0073 (7 April 1986), ADA173990

JONES, G.M., and MURPHY, V.J. (Weston Geophysical Corp., Westboro, MA)
Simulated Ground Response Using Non-Linear Elastic Moduli
AFGL-TR-85-0065 (15 March 1985), ADA160590

JORDAN, T.H. (Massachusetts Inst. of Tech., Cambridge, MA)
Investigations of Eurasian Seismic Sources and Upper Mantle Structure
AFGL-TR-85-0206 (30 June 1985), ADA165228

KUO, J.T., and TENG, Y.-C. (Columbia Univ., New York, NY)
Ground Response in Alluvial Basins Due to Seismic Disturbances
AFGL-TR-85-0062 (March 1985), ADA162467

MCEVILLY, T.V., JOHNSON, L.R. (Univ. of California, Berkeley, CA)
Regional Studies with Broadband Data
AFGL-TR-86-0124 (6 June 1986), ADA172317

NUTTLI, O.W., MITCHELL, B.J., and HWANG, H.J. (St. Louis Univ., St. Louis, MO)
Attenuation of Seismic Waves at Regional Distances
AFGL-TR-85-0185 (15 August 1985), ADA164617

RAPP, R.H. (The Ohio St. Univ., Columbus, OH)
Detailed Gravity Anomalies and Sea Surface Heights Derived from GEOS-3/SEASAT Altimeter Data
AFGL-TR-85-0191 (August 1985), ADA166593
The Study of Gravity Field Estimation Procedures
AFGL-TR-85-0278 (September 1985), ADA164564

SHAPIRO, I.I. (Harvard Coll., Obs., Cambridge, MA)
Research in Geodesy and Geophysics Based Upon Radio Interferometric Observations of Extragalactic Radio Sources
AFGL-TR-86-0234 (October 1986), ADA177527

SIMPSON, D.W. (Columbia Univ., Palisades, NY)
Synthetic Seismograms, Graphic Software and Computer Facilities
AFGL-TR-85-0306 (May 1985), ADA166517

STEVENS, J.L. (S-Cubed, La Jolla, CA)
Estimation of Scalar Moments from Explosion-Generated Surface Waves
AFGL-TR-85-0097 (April 1985), ADA160327

SÜNKEL, H. (The Ohio St. Univ., Columbus, OH)
On The Reduction of Gravity Data for the Prediction of the Gravity Disturbance Vector at Altitudes
AFGL-TR-85-0084 (July 1984), ADA160358
An Isostatic Earth Model
AFGL-TR-85-0239 (September 1985), ADA164608

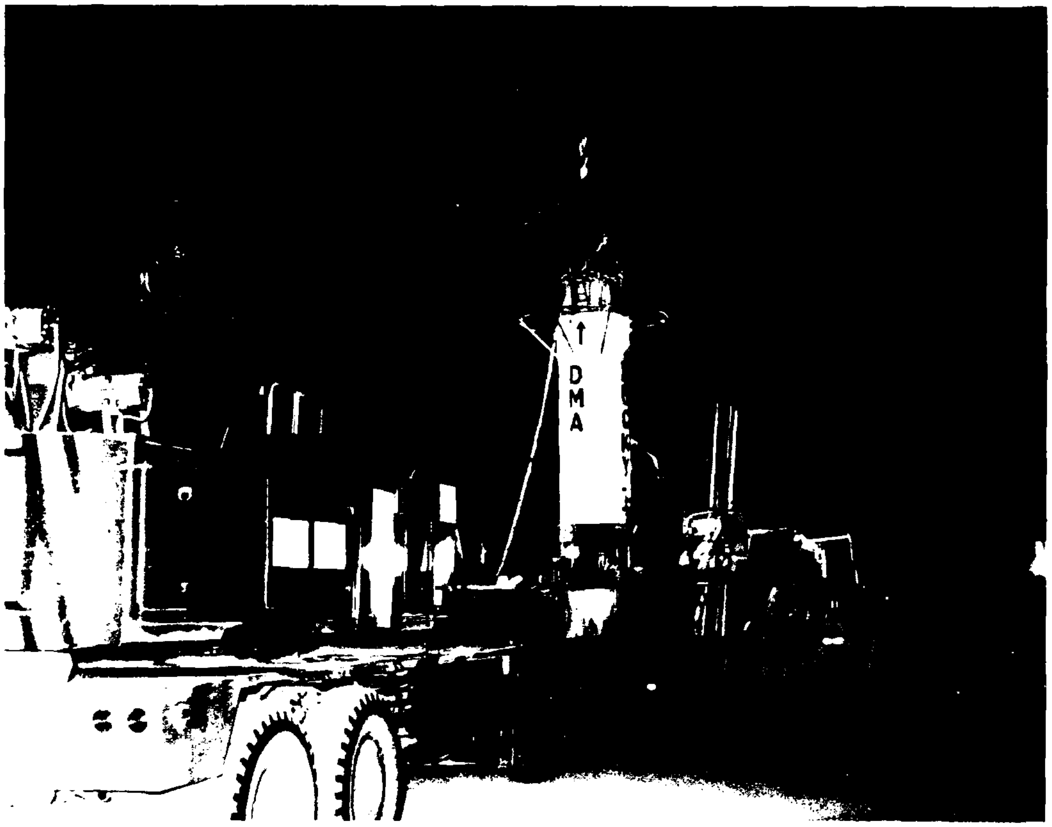
SZABO, B. (The Ohio St. Univ., Columbus, OH)
The Estimation of the Earth's Gravity Field
AFGL-TR-86-0125 (June 1986), ADA172177

TOKSOZ, M.N., DAINTY, A.M., and CHARRETTE, E.E. (Massachusetts Inst. of Tech., Cambridge, MA)
Development of Ultrasonic Modelling Techniques for the Study of Seismic Wave Scattering Due to Crustal Inhomogeneities
AFGL-TR-86-0078 (March 1986), ADA170062

UOTILA, U.A. (The Ohio St. Univ., Columbus, OH)
Theoretical Studies on Determinations, Predictions, and Accuracies of Geodetic Parameters and Gravimetric Quantities
AFGL-TR-86-0097 (May 1986), ADA170846

WHITE, J.V. (Analytic Sciences Corp., Reading, MA)
A Statistical Gravity Model for Northern Texas
AFGL-TR-85-0037 (19 November 1984), ADA160474

WOJCIK, G.L., and MAK, R. (Weidlinger Assoc., Palo Alto, CA)
A Numerical Study of Diffraction in Reentrant Geologic Structure
AFGL-TR-85-0158 (15 July 1985), ADA168562



Balloonborne Gravity Measurements Payload Sponsored by DMA Being Readied for Launch on the Pad.

VIII AEROSPACE ENGINEERING DIVISION

The Aerospace Engineering Division supports other divisions of AFGL by providing probe-vehicle systems, balloons, and sounding rockets to carry the instruments that gather data for scientists in their studies of the environment. Our engineers also manage Laboratory-initiated experiments to be flown on satellites of the Air Force Space Test Program, including the space shuttle.

To provide modern, efficient probe-vehicle systems, the Division conducts a technology base program in payload design, telemetry instrumentation and techniques, tracking, and command and recovery systems. Fewer payloads are being flown than in the past, but the payloads are more complex. Increased emphasis has also been placed on reliability. Expensive sensors and payloads must now be recovered and reused. Modern solid-state sensors have an almost limitless ability to generate data. This has taxed both our airborne and ground capability to transmit and process data. Faster, more efficient data-handling is therefore a major thrust of our technology base program.

We can conduct rocket and balloon flights from anywhere in the world. A majority, however, are flown from White Sands Missile Range, New Mexico, where restricted air space, optical tracking, precision radar, and excellent conditions for payload recovery are available. Rockets are launched from a Navy facility at White Sands Missile Range shared with other users. Balloons are launched from a permanent balloon-launch facility at Holloman AFB, within White Sands Missile Range, manned by AFGL Detachment 1.

BALLOON PROGRAM

The Aerospace Engineering Division designs and develops completely instrumented, large balloon systems for in-situ measurements in the stratosphere and conducts developmental tests of instruments intended for space operations. The experimenters are scientists from the other AFGL divisions, Systems Command, agencies in the Department of Defense, and other government agencies.

The balloon program manager and assigned project officer work closely with the scientific investigators from the inception of a balloonborne experiment. Their collaboration ensures that all components of the payload will be environmentally suitable, and the balloon instrumentation will in fact provide the electrical power budget, data-handling capability, radio-command facilities, flight trajectory, and payload-recovery operations required to fulfill the experimental objectives.

Mammoth free-balloon systems, unlike other atmospheric probes, ascend slowly, typically 900 feet per minute, and can remain aloft for hours, or even days if so designed. Payloads can be almost any size or shape that can be handled at the launch site. Instruments can be reeled down, and up again, thousands of meters below the balloon whenever the investigator so commands. Small packages or individual sensors can be placed on top of the balloon.

Many AFGL flights are launched from our Balloon Facility at Holloman AFB. Our mobile facilities are used to launch from remote locations, or from strategically-located off-base sites chosen so that the local wind fields carry the balloon directly over a designated test area.

Microelectronics and today's computer technology have vastly improved the options available to balloon experimenters. Heavy, delicate, complex instruments are being flown and recovered for reuse. While a flight is in progress, selected data are reduced immediately and displayed at the control center for quick-look appraisal in whatever format the experimenter has specified. Up to several hundred interference-free radio commands are available to alter or manipulate the experimental payload. AFGL is exploiting these capabilities by flying innovative payloads to obtain first-time measurements having immediate applications to scientific and military needs, as indicated below.

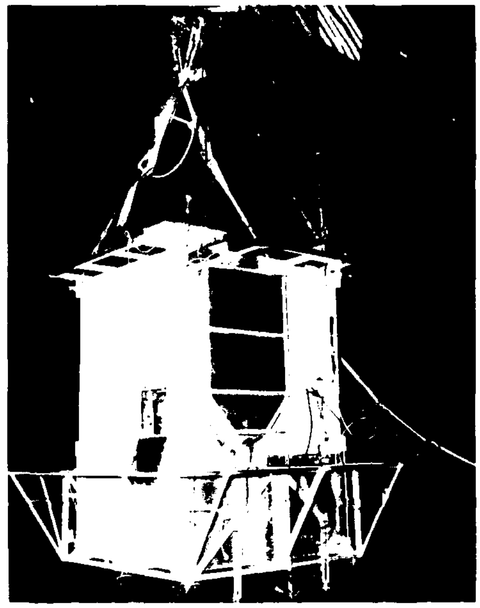
Airborne Low Frequency Atmospheric Noise (ALFAN): The Rome Air Development Center's balloonborne low-frequency noise experiment carries an antenna system to measure low-frequency noise that interferes with longwave communications (see the figure). These measurements were made during periods of local lightning activity. During a successful flight in 1986 from Roswell, New Mexico, noise data were collected from several different directions.

Balloonborne Gravity Measurements: At high altitudes, values of acceleration due to gravity are estimated from models having unverified accuracies. This deficiency can contribute to significant missile guidance errors. The Earth Sciences Division's Balloonborne Gravity Measure-and unloading characteristics. All Astrofilm E tests were completely successful. During the flight test in December 1986, balloon dynamics during ascent were monitored and photographed by a NASA U-2 aircraft.

Airborne Low-Frequency Atmospheric Noise (ALFAN) Experiment on Pad before Launch.

ments program continued with a measurements flight in October, 1985. Incorporated in this 1815 pound payload were a Vibrating String Accelerometer and a Global Positioning Satellite (GPS) receiver. The new data acquired should lead to significant reductions in the miss errors on the test range or at operational missile launch sites.

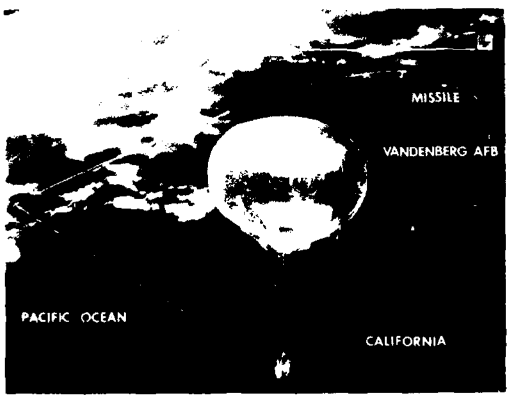
Balloon Film: The Aerospace Engineering Division has continued support for the development and testing of a new balloon film. A full-scale balloon, 2.9×10^6 ft^3, made from Astrofilm C was tested and failed during flight. The next generation, Astrofilm E, was test-flown with loads ranging from 50 percent to 90 percent of the maximum recommended load. These balloons were also tested for rapid rise



BIMS Payload. (Every AFGL balloon payload undergoes a complete final checkout on the launch pad just before flight.)

BIMS: A Balloon-borne Ion Mass Spectrometer, developed by the Ionospheric Physics Division, was flown from the Balloon Flight Test Facility at Holloman AFB in May and October, 1985 (see the figure). Data were collected from 96,000 ft to 132,000 ft altitudes from early morning through sunset. These data provide information on the ionic conditions in a region critical to the understanding and modeling of extremely low frequency radio propagation.

Denver I, II: Two infrared sensing platforms were flown for the University of Denver under the sponsorship of the Optical Physics Division (see the figure). These efforts collected data relevant to aerosol change during sunrise and sunset.

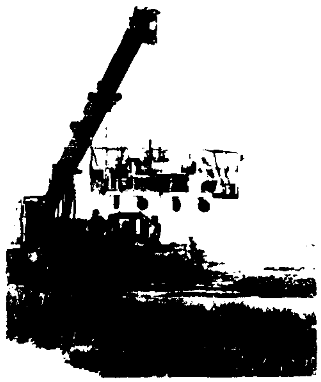


Kestrel Scenario. (The scientific payload beneath the 6.0×10^6 ft^3 balloon is observing second and third stage ignition of an ICBM.)

KESTREL: An experiment flown as part of the Plume Radiance Observation Experiment (PROBE) was launched from the airstrip at Ramona, California. A 5.0×10^6 ft^3 balloon carried a stabilized pointing platform to 90,000 ft (see the figure). From this altitude solar background gain concepts were proved, and tracking and pointing hardware were qualified. An array of cameras (infrared, visual and ultraviolet) were mounted on the optical bench.

Pathfinder: This Aerospace Engineering Division development was used operationally during the spring and summer of 1986. Although designed for the 132,000 ft region, the balloons were scaled down from 144,000 to 57,000 ft^3 for an operational altitude of 76,000 ft to provide a ballistic trace for the Scribe 99 project.

Scribe: This interferometer experiment gathered high-resolution infrared spectral measurements from stratospheric levels. The Optical Physics Division's instrument observed absorption and emission characteristics along the horizontal and downlooking atmospheric paths through which long-range target-detection systems must penetrate.



SCRIBE 99 Interferometer Payload During Test Launch Run.

Scribe 99: The Scribe interferometer was fitted with pointing mirrors to observe a ground-based gas plume from an altitude of 76,000 ft. This flight, launched from Roswell in August, 1986, was required to pass over a predesignated ground target. Before overflying the target, the on-board sensors were calibrated by sighting on a superheated tethered hot-air balloon located upstream from the target (see the figure). Pointing the sensors to the target area was accomplished by a manually operated joy-stick.

Tethered Balloons: The Aerospace Engineering Division has a working inventory of large tethered aerostats. They are regularly used for atmospheric measurements, surveillance exercises, mounting targets for advanced radar and weapons qualifications, and dropping modules to observe their performance before space operation. The Division is also developing new, dedicated tethered systems for special military applications. These new systems use computer-designed aerostat shapes that fly with good stability in very high winds, and new lightweight, strong hull materials and cables. For communications and other long-endurance applications that should not be interrupted, tether cables are now being designed to incorporate an electrical conduit that delivers power from a ground-based source up to the payload.

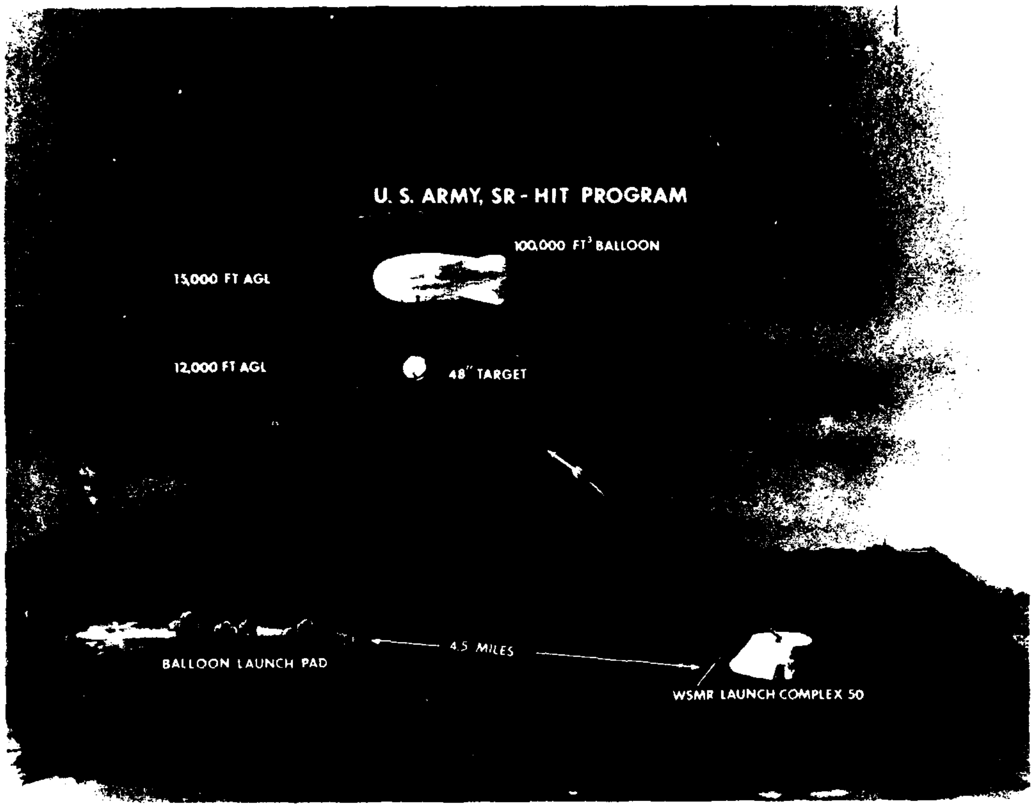
Army Missile Command: A 100,000 ft^3 tethered aerostat and its associated equipment are being furnished to the Army Missile Command for a classified project. The AFGL balloon crews are working with the Army crews to provide training in tethered operations so that the Army can conduct its own balloon operations. The balloon is tethered at 7900 ft above ground level for this operation.

EXDRONE: A series of tethered aerostat flights were conducted during September, 1985, in support of the Marine Corps Education and Development Center. These flights were conducted from a remote desert site in Utah to obtain data on the effective range and efficiency of a prototype airborne tactical jammer.

HY-WIRE: This NASA experiment to measure electrical potential in the atmosphere was conducted from Holloman AFB, New Mexico, simultaneously with a more extensive experiment being conducted from Fort Greeley, Alaska. The Aerospace Engineering Division conducted the CONUS effort while a NASA crew did the Alaskan one. On both experiments, long wire conductors were held aloft by tethered balloons. During the first field effort, the mission success criterion was met by making twenty hours of simultaneous comparative measurements.

ILC Tether Test: A new 45,000 ft^3 tethered aerostat was flight-tested by the Aerospace Engineering Division at SCAT site located on the White Sands Missile Range. This aerostat uses blowers rather than ram air to maintain inflation of the ballonet and tail fins. Materials development has resulted in a stronger and lighter hull fabric, which substantially reduces the balloon instability characteristics compared with other designs currently in the inventory. This increased stability will greatly enhance our capacity to conduct the Optical Physics Division's lidar experiment on a tethered balloon. The demands on the pointing control are greatly reduced.

SR-HIT: AFGL flew a 100,000 ft^3 tethered aerostat carrying a missile target on the White Sands Missile Range for the U.S. Army's Small Radar Homing Intercept Program to a record altitude of 21,120 ft MSL. The 48 inch diameter spherical target, suspended in-line 900 meters below the balloon, had to remain positioned within a prescribed intercept scoring box at 12,000 ft above the ground. This was accomplished by using a modified M47 Patton tank as the tether ground anchor and moving the tank as required to compensate for changes in the wind direction. In the live test, a direct hit was scored on the target, which severed the



US Army Small Radar Homing Intercept Technology (SR-HIT) Program Scenario.

balloon tether line (see the figure). Safety quick-deflate devices brought the balloon down within the range boundaries.

TAAP: The Tethered Aerostat Antenna Program, conducted for the Defense Communications Agency, moved out of the initial testing, Phase I, into Phase II, test planning for system performance, scheduled for testing in 1987. This demonstration system is intended for rapid deployment under simulated post-attack conditions. The TAAP system is currently undergoing a number of engineering modifications, including the installation of a new 25W vlf transmitter.

Balloon Systems Development: During 1985-86 the Aerospace Engineering Division continued in-house studies and hardware development to modernize and improve balloon instrumentation and vehicle capabilities. The multiple-address digital command system was upgraded to provide 950 commands secure from interference, which produces false commands. It has independent address and status verification and is operable with every hf, uhf, and vhf radio frequency assigned to AFGL. A payload motions package contains sensitive three-axis gyros and accelerometers to measure the very small rotations and vibrations of gondolas carrying orientation or rate-sensitive instruments. The data are also needed for designing pointing controls and stabilized platforms.

Work is in progress to develop a balloon tracking system based on the multi-satellite Global Positioning System. By interfacing an on-board GPS receiver with our balloonborne telemetry system, position, velocity and GPS time measurements will be down-linked, displayed, and recorded at AFGL ground stations. This tracking system will provide accurate tracking data anywhere in the world.

The tracking and communications system used aboard the chase aircraft was upgraded to provide more reliable communications transmitted from a small aircraft.

For the gravity project, a slipring assembly was developed which decouples the balloon motions from the gondola. This decoupling provides a quieter and more stable platform for the sensitive measurements required.

A new ballast-valve assembly was developed which reduces the power requirements for ballasting by a factor of fifteen. This valve is now used routinely on AFGL balloon flights.

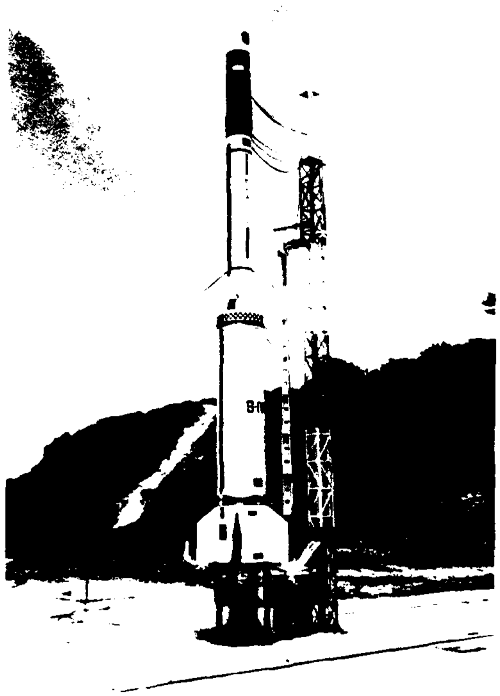
SOUNDING ROCKET AND SPACE SHUTTLE PROGRAMS

The Aerospace Engineering Division is responsible for the development, management, and launch of rocket-payload systems for AFGL's research rocket program and for the integration of AFGL experiments on free-flying and shuttle-based spacecraft. With a history that includes the instrumenting and launching of more than 1000 sounding rockets since 1946, the high rate of successful launches continues.

In this time period, five sounding rockets were launched, one each from White Sands Missile Range, New Mexico, and Poker Flat Research Range, Alaska, our normal launch sites. One vehicle was launched from an expeditionary site at Sondrestrom, Greenland, and two were launched from Natal, Brazil. Four payloads are in fabrication for launch in 1987 and four others are in design for launch in later years. Many of our current efforts are in support of the Strategic Defense Initiative program.

We continue to provide support to experimenters by selecting launch vehicles; designing, fabricating, and integrating experimental payloads; conducting test launch operations; and providing for telemetry and trajectory data collection. As scientific requirements lead to the evolution of more sophisticated payloads, both the size and complexity of payloads continue to increase. Payloads exceeding 2000 pounds, such as those flown on Aries type rockets, have become routine. Increased data-handling requirements have led to the use of computer-based technology in both airborne and ground-based support systems. The need to continually advance the state-of-the-art of rocket instrumentation has required a corresponding emphasis on our in-house engineering development program. Research has continued in the areas of micro-processor-based adaptive telemetry systems, intelligent data-processor systems, and command and control systems.

HARP: The High Altitude Recovery Program (HARP) was a project in cooperation with the Brazilian Air Force to develop,



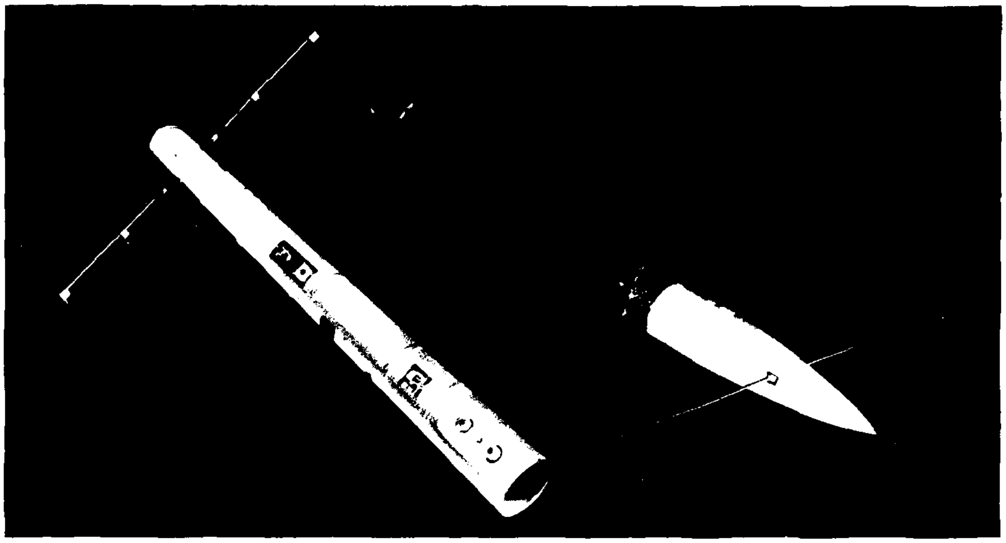
High Altitude Recovery Program SONDA IV Rocket Vehicle in Natal, Brazil.

test, and flight-qualify a low-cost water-recovery system with a large payload and a high-altitude capability. The concept utilized aerodynamic braking by appropriately positioning the center of gravity of the reentry body so that a standard recovery system could be safely deployed. For water recovery, a flotation bag carrying a dye marker, radio beacon, and strobe lights was inflated with cold gas at main chute deployment. On November 19, 1985, HARP was launched aboard a SONDA IV rocket from Natal, Brazil (see the figure). The system successfully floated the 750 lb payload, which entered the water from an apogee of 666.4 km.

Polar Ionospheric Irregularities Experiment Field Operations at Sondrestrom AFB, Greenland Launch Site.

PIIE: In March 1985, AFGL flew the highly successful Polar Ionospheric Irregularities Experiment (PIIE) payload from Sondrestrom Air Base, Greenland (see the figure). This payload was carried aboard a Terrier-Black Brant (BBIX) sounding rocket to an apogee of 425 km and acquired data used to define polar cap ionospheric structure and the dynamics of a stable auroral arc. The AFGL Airborne Ionospheric Observatory (C-135 aircraft) was positioned over the launch site. It evaluated the auroral conditions in-situ and made the rocket launch decision. The coordination enabled the sounding rocket payload to pierce the auroral arc above 400 km.

BERT: The BERT-1 (Beam Emission Rocket Test) payload was successfully launched from White Sands Missile Range, New Mexico, on June 15, 1985. A Nike Black Brant (BBVII) rocket was used to launch the payload to an altitude of 240 km. BERT-1 was a mother/daughter payload (see the figure). The mother (BERT) consisted of five sections instrumented with experiments and side-mounted booms and sensors for conducting electron beam tests. The daughter (ERNIE)



Beam Emission Rocket Test Black Brant VII Rocket Payload (mother portion at left; ejected daughter Ernie at right).

(Ejected Rocket Nose to Measure Induced Emission) was a nose cone section instrumented with experiments to measure induced emissions. The BERT/ERNIE payload weighed 810 pounds, measured 17.26 inches in diameter and was 222 inches long. The payload contained one separation system used to eject ERNIE before initiation of despin. Mother/daughter separation occurred at an altitude of 110 km. BERT and ERNIE had independent systems. Each contained power, control, telemetry, tracking, and electronic support systems. BERT had two telemetry links and a PCM link for the instruments and housekeeping data. A fiberglass section isolated the telemetry section from the booster ignitor can. Total BERT weight excluding the ignitor can, despin, and destruct system was 652 pounds. ERNIE weighed 158 pounds and was 96 inches long from nose tip to the Electron Density Sensor fully extended on the platform mechanism. An FM/FM telemetry system was used for ERNIE.

Space Shuttle Systems: Much of the work in the Aerospace Engineering Division is now in space shuttle payload systems. Because of the unfortunate Challenger accident in January, 1986, however, scheduled AFGL missions utilizing this vehicle were on hold. The CIRRIS 1A (Cryogenic Infrared Radiance Instrumentation for Shuttle) has completed exhaustive space simulation testing at the Jet Propulsion Laboratory and most of the integration activity at Lockheed Missiles and Space Corporation. It has been returned to Utah State University, where detailed instrument calibration is underway.

The division developed for Space Division a generic GAS (Get Away Special) support system for shuttle experiments under its technology base program. As part of that effort, in-house personnel have designed, developed, and tested a microprocessor controller and data storage system (see the figure). These systems have been integrated into their first mission application on VIPER (Visual Photometric Experiment), a GAS project for the Optical Physics Division.

Significant engineering support was also provided to IMPS (Interaction Measurements Program for Shuttle) for safety engineering, analysis, and testing.

Technology Base Development: The increased emphasis on the use of the space shuttle and the trend toward more complex and costly experiments have directed our efforts in technology base development toward high-reliability high-performance data handling systems. Development focused on accommodating higher data rates and greater data storage.

We continued to update our real-time and quick-look ground station capability. Software has been developed for our five PDP-11 based stations to provide "look-alike" performance and flexibility to operators. A project to develop a second generation computer-controlled data handling and display system is nearly complete and will utilize the high-speed, color-display IBM AT personal computer.

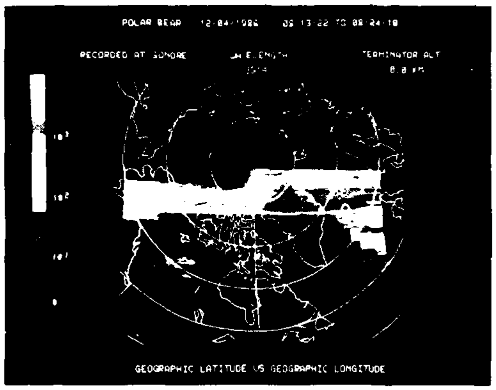
We have completed a study of high-density digital-recording feasibility. This study revealed that laser disk technology, while rapidly evolving, may be well suited to ground and flight-based systems requiring high recording rates and capacities. Intense research and development continues in this technical area. Instrumentation is also under development using digital techniques to better measure and characterize the flight acoustic and vibration environment aboard rockets and shuttle.

DATA SYSTEMS ANALYSIS

The Data Systems Branch of the Aerospace Engineering Division designs, develops and implements mathematical techniques and computational methodologies for processing and analysis of scientific data recorded from ground and space-probe instrumentation.

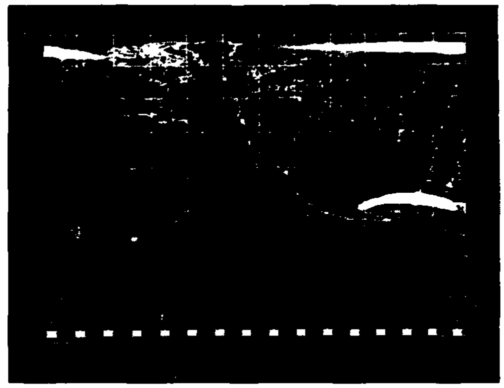
Telemetry Data Processing: The Telemetry Data Processing section supports laboratory projects in the initial data-processing tasks required to convert data recorded during satellite, balloon, and rocket flight operations into computer-compatible formats. Data are converted from analog to digital formats, edited, time-correlated, and displayed. Recent enhancements to the telemetry data processing station include the replacement of the central processing unit with a VAX-750, addition of high bit-rate telemetry processing units, and additional storage capabilities. A telemetry data processing system called ARTICS (automated real time instrumentation control system) was also developed and installed to increase capabilities to handle large, sophisticated data recording media now being used in space-probe data-gathering projects. ARTICS is menu-driven for ease of operation and allows hardware and software to be brought on line by the console operator. It provides quick-look displays during the acquisition process and the capability for multiple data-stream processing.

Data Systems: The Data Systems section provides centralized support to large data-gathering space experiment projects. This support is given in two phases: (1) pre-launch, which is normally a team ef-

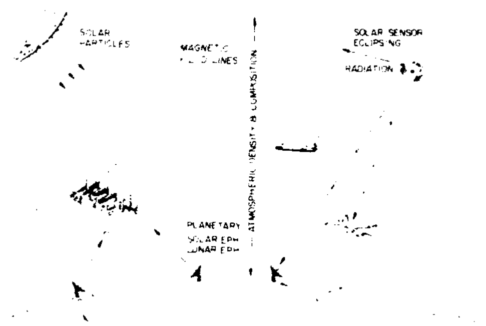


Polar Bear AIRS Automated Color Graphic Presentation.

fort with project scientists and computer analysts working on planning functions required to design an effective approach to processing large volumes of data to meet project goals and milestones; and (2) post-launch, which is mainly the systematic implementation of developed data systems with recorded flight data to produce and maintain a geophysical parameter database. The functions performed by the analysts in support of the reduction and analysis of space-probe data include: data focal point for AFGL experiments, dealing with outside agencies and data processing facilities; design and development of integrated data-management approaches and subsequent documentation in a data support plan; participation in data-analysis task groups with outside agencies to develop coordinated data-processing approaches to multi-agency, multi-probe satellite projects; development of data-support systems, generation of compacted geophysical unit databases, display of time histories of measured environmental parameters, and archiving of final history databases, maintaining and upgrading interactive graphic display capabilities; and developing special display techniques (contour, three-dimensional, spectrogram, color) (see the figure).



AFGL Interactive Targeting System (AIRS) Shuttle Ground Track Sensor Line-of-Sight Projections.



Space Vehicle Ephemerides and Model Calculations Supported by the Data Systems Branch.

The AFGL Interactive Targeting System (AITS) was developed during this period. AITS is designed to provide premission and on-orbit planning support for the CIRRIS 1-A Project. It is a computer-

VIPER (Visual Photometric Experiment) Integration Inside High Bay of New AFGL Payload Building.

based system which displays shuttle position and sensor line-of-sight in various formats. Color graphic displays depict the world map, the celestial sphere, and the probability of auroral activity (see the figure). This system provides researchers with the tools needed to evaluate, in near real time, the shuttle and sensor orientation during data-gathering portions of the orbit, and to view the dynamics of the shuttle attitude and the auroral conditions. It also supplies information on line-of-sight and field-of-view for earth and space targets. The system is user-friendly and provides the researcher with an interactive menu to select the desired computation or display. Although the AITS system was developed to support the CIRRIS-1A Project, it can be applied to any orbit sensor whose pointing direction can be calculated. The system is especially useful for sensors whose pointing direction can be controlled.

Orbital Analysis: The Orbital Analysis section provides analytic support and corollary data to researchers involved with interpreting flight probe data (see the figure). The support is given in four major categories: (1) calculating vehicle trajectories and attitude; (2) generating time-history databases of geophysical support parameters; (3) developing and maintaining computational routines to calculate environmental and space-vehicle model parameters; and (4) developing analytical capabilities for the laboratory, including optimization methods, mathematical systems modeling, spectral analysis, numerical analysis, and statistical analysis. Specific support provided researchers on a continuing basis includes rocket and satellite trajectory computations; satellite reentry predictions; satellite ground-track projections; pre-launch satellite orbit predictions; maintaining models to calculate parameters for magnetic field, atmospheric density and composition, particles, spacecraft charging, spacecraft contamination, and the auroral oval; spacecraft attitude determination; and maintaining a database of geophysical parameters. Instrumentation is also under development using digital techniques to better measure and characterize the flight acoustic and vibration environment aboard rockets and the shuttle.

In July, 1986, the Air Force dedicated the new Payload Test and Integration Facility in the AFGL complex. This new wing, built to support aerospace engineering testing, provides a tremendous increase in capabilities for assembly, integration, and testing of balloon, sounding rocket, and shuttle payloads. The facility includes a complete telemetry ground station for real-time data acquisition and assessment. Environmental test equipment is available for thermal, vacuum, vibration, and shock testing of both components and assemblies (see the figure). A new large vibration test facility has been delivered and is being installed. The 100 ft by 50 ft high bay (30 ft high) and two X-Y translating cranes can handle payloads that weigh over 5000 lbs. A class 100 clean room is located in the bay.

PUBLICATIONS
JANUARY, 1985 - DECEMBER, 1986

CARTEN, A.S., JR. (AFGL); and STOMPS, T.F. (TCOM Corp., Columbia, MD)
The Tethered Aerostat Antenna Program (TAAP) Demonstration Phase
Proc. AIAA 6th Lighter-than-Air Systems Conf., (16-24 June 1985)

THURBER, J.B., and WILSON, G.S., 1LT
A Payload Support System for Expe. nents Using the Get Away Special
Proc. 7th AIAA Sounding Rocket Conf. (28-30 October 1986)

PRESENTATIONS
JANUARY, 1985 - DECEMBER, 1986

JACOBS, R.E., and KREBS, C.P.
High Altitude Recovery Program (HARP)
7th AIAA Sounding Rocket Conf., Ocean City, MD (28-30 October 1986)

LOCKER, A.J., III, WALTERS, R.F. (AFGL); and FEKEN, C.D. (Oklahoma St. Univ., Stillwater, OK)
The Selection of an Angular Velocity Transducer for an Approximate Axially Symmetric Body
7th AIAA Sounding Rocket, Balloon and Related Space Systems Conf., Ocean City, MD (28-30 October 1986)

SCARBORO, R.E. (Space Vector Corp., Northridge, CA); HOWARD, C.D., and JACOBS, R.E. (AFGL)
High Altitude Recovery Program (HARP)
7th ESA Symp. on European Rocket and Balloon Programs and Related Research, Leon, Norway (5-11 May 1985)

TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

DEGGES, T.C. (Visidyne, Inc., Burlington, MA) and D'AGATI, A.P. (AFGL)
A User's Guide to the AFGL/Visidyne High Altitude Infrared Radiance Model Computer Program
AFGL-TR-85-0015 (October 1984), ADA161432

DWYER, J.F.
Factors Affecting the Vertical Motion of a Zero-Pressure, Polyethylene, Free Balloon
AFGL-TR-85-0130 (31 May 1985), ADA164596

CONTRACTOR TECHNICAL REPORTS
JANUARY, 1985 - DECEMBER, 1986

ANDERSON, R.D., and ENG, R.C. (Northeastern Univ., Boston, MA)
Manacle Band Release Mechanisms
AFGL-TR-85-0116 (May 1985), ADA168303

BUCK, R.F.
Instrumentation Research and Support Services
AFGL-TR-85-0255 (30 September 1985), ADA169378

CUNNINGHAM, L., BAWCOM, D., and SHAW, H. (Physical Science Lab., Las Cruces, New Mexico)
Engineering and Instrumentation Support of AFGL Rocket Research Program
AFGL-TR-86-0242 (30 September 1986), ADA179257

DELAURIER, J.D., and DELEEUW, J.H. (Univ. of Toronto, Ontario, Canada)
Balloon Instrumentation Engineering and Development
AFGL-TR-85-0258 (15 October 1985), ADA170225

GWINN, C.M. (Oklahoma St. Univ., Stillwater, OK)
LAIRTS Pixel Data Formatter
AFGL-TR-85-0192 (August 1985), ADA164512

MORIN, R.L., and SWEENEY, C.B. (Northeastern Univ., Boston, MA)
Model 2480 Timer
AFGL-TR-85-0112 (November 1982), ADA165281

PEARSON, J., and GRAYSON, J. (Oklahoma St. Univ., Stillwater, OK)
IRIG Format "B" Decoder
AFGL-TR-85-0193 (June 1985), ADA165225

TRACY, F.J., and TWEED, H.M., JR. (Northeastern Univ., Boston, MA)
Nicad Battery Packages
AFGL-TR-86-0052 (February 1986), ADA170140

WILLIS, J.L. (New Mexico St. Univ., Las Cruces, NM)
SHARP (Stabilized High Altitude Research Platform)
AFGL-TR-85-0056 (September 1985), ADA164459

APPENDIX A

Service On International Committees By AFGL Scientists

Committee on Space Research of the International Council of Scientific Unions (Space Studies of the Upper Atmosphere of the Earth and Planets, Including Reference Atmospheres, Program Committee, Executive Council, URSI/COSPAR Task Group on the International Reference Ionosphere, Subcommission F-2 on Radiation Biology, Interdisciplinary Scientific Commission for Life Sciences and Related to Space, Subcommission E-2 on Solar Physics, Interdisciplinary Scientific Commission E on Research in Astrophysics from Space)

International Agency Coordinating Committee on Middle Atmosphere Programs

International Association for Meteorology and Atmospheric Physics (Working Group on Aerosols and Climate)

International Association of Geomagnetism and Aeronomy (committees on Magnetospheric Phenomena, Electro-dynamics of the Middle Atmosphere, Pulsation, Quantitative Magnetospheric Models, and the US National Committee)

International Committee for Fourier Transform Spectroscopy

International Radiation Commission (Remote Sensing Group)

International Scientific Radio Union (URSI) (US National Committee, Commission G; Chair, Working Group 12 "On Studies of the Ionosphere Using Beacon Satellites")

International Union of Geodesy and Geophysics

NATO Panel AC243, Panel IV (Chairman), RSG8, RSG14, NATO Advisory Group on Aerospace Research and Development (Electro-Magnetic Wave Panel)

Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) (Monitoring Sun-Earth Environment Committee, Study of Travelling Interplanetary Disturbances)

World Data Center A for Solar-Terrestrial Physics

World Meteorological Organization (committees on Atmospheric Spectroscopy, Intercomparison of Transmittance Radiance Algorithms, Atmospheric Science)

APPENDIX B

Service On National Committees By AFGL Scientists

Acoustics, Speech and Signal Processing Society (Spectrum Estimation and Modelling Committee)

Ad Hoc Committee on Laboratory-University Relationships of the Office of the Undersecretary of Defense Research and Engineering

American Geophysical Union (Committee on Atmospheric and Space Electricity)

American Institute of Aeronautics and Astronautics (National Technical Committee of Plasma-dynamics and Lasers, Atmospheric Environment Panel)

American Meteorological Society (Committee on Satellite Meteorology and Oceanography, Committee on Mountain Meteorology)

Committee on TIROS Operational Vertical Sounder

Department of Commerce (advisor to National Geophysical Data Center)

Department of Defense (Chair, Conference on Effects of Environment on Systems Performance, Representative Committee on Nuclear Phenomenology Affecting Space Systems; National Storm Program)

Department of State (Solar-Terrestrial Physics Committee, Geophysics Commission, Pan American Institute of Geography and History, Organization of American States)

Executive Committee of the Infrared Information Symposia

Fleming Medal Subcommittee of Committee of Fellows, AFSC/NASA Spacecraft Environmental Interactions Technology Steering Committee

Interagency Committee on Sensing from Aircraft

Interdepartmental Committee for Meteorological Services and Supporting Research, Space Environment Forecasting (USAF technical advisor)

NASA Ozone Assessment Panel

National Academy of Sciences (Committee on Solar-Terrestrial Research)

National Research Council, Geophysics Research Board, Committee on Geophysical Data, Chairman, Advisory Panel for Solar-Terrestrial Physics

Office of Science Technology Policy of the President (Planning Committee of Interagency Coordinating Committee on Solar Terrestrial Relations)

Science and Engineering Support Group for Surveillance, Acquisition, Tracking and Kill Assessment of the Strategic Defense Initiative Organization Tri-Service (Clouds Modeling Committee, MIL-STD-2102 Committee, Chair)

APPENDIX C

AFGL PROJECTS BY PROGRAM ELEMENT FY 1985

Program	Project Number and Title	
61101F	*ILIR*	In-House Laboratory Independent Research
61102F	*DEFENSE RESEARCH SCIENCES*	
	2303G1	Upper Atmosphere Chemistry
	2309G1	Geodesy and Gravity
	2309G2	Earth Motion Studies
	2310G1	Molecular and Aerosol Properties of the Atmosphere
	2310G3	Upper Atmosphere Composition
	2310G4	Infrared Atmospheric Processes
	2310G6	Local Ionospheric Processes
	2310G7	Atmospheric Dynamic Models
	2310G8	Advanced Weather Satellite Techniques
	2310G9	Global Ionospheric Dynamics
	2311G1	Energetic Particles in Space
	2311G2	Magnetospheric Plasmas and Fields
	2311G3	Solar Research
62101F	*GEOPHYSICS*	
	3054	Infrared Target and Background Signatures
	4643	Ionospheric Specification
	6670	Atmospheric Science and Technology
	7600	Terrestrial Geophysics
	7601	Magnetospheric Effects on Space Systems
	7659	Aerospace Probe Technology
63410F	*SPACE SYSTEMS ENVIRONMENTAL INTERACTIONS TECHNOLOGY*	
	2821	Space Systems Design/Test Standards
	2822	Interactions Measurement Payload for Shuttle (IMPS)
	2823	Charge Control System
63707F		
	2688	*WEATHER SYSTEMS (ADVANCED DEV.) BATTLEFIELD WEATHER SYSTEMS*
	2781	Next Generation Weather Radar
65502F	SBIR	*SMALL BUSINESS INNOVATION RESEARCH*

In addition to the continuing Air Force funded projects cited above, AFGL participates in joint programs supported by the following agencies:

1) U.S. Air Force
   - Space Division
   - Ballistic Missile Office
   - Air Force Weapons Laboratory
   - Air Weather Service
   - Electronic Systems Division
2) Defense Advanced Research Projects Agency
3) Defense Mapping Agency
4) Defense Nuclear Agency
5) Defense Communications Agency
6) Department of Energy
7) National Aeronautics and Space Administration
8) Navy

AFGL PROJECTS BY PROGRAM ELEMENT
FY 1986

Program	Project Number and Title	
61101F	*ILIR*	In-House Laboratory Independent Research
61102F	*DEFENSE RESEARCH SCIENCES*	
	2303G1	Upper Atmosphere Chemistry
	2309G1	Geodetic Sciences
	2309G2	Seismology
	2310G1	Molecular and Aerosol Properties of the Atmosphere
	2310G2	Infrared Background Measurements
	2310G3	Upper Atmosphere Composition
	2310G4	Infrared Atmospheric Processes
	2310G5	Infrared Airglow and Auroral Models
	2310G6	Local Ionospheric Processes
	2310G7	Atmospheric Dynamic Models
	2310G8	Atmospheric Specification
	2310G9	Global Ionospheric Dynamics
	2311G3	Solar Research
	2311G4	Solar Terrestrial Interactions
	2311G5	Magnetospheric Processes
62101F	*GEOPHYSICS*	
	3054	Infrared Targets and Backgrounds
	4643	Ionospheric Specification
	6670	Atmospheric Science and Technology
	7600	Terrestrial Geophysics
	7601	Magnetospheric Effects on AF Systems
	7659	Aerospace Probe Technology
	7661	Spacecraft Environment Technology
	7670	Optical/IR Properties of the Environment
63410F	*SPACE SYSTEMS ENVIRONMENTAL INTERACTIONS TECHNOLOGY*	
	2821	Space Systems Design/Test Standards
	2822	Interactions Measurement Payload for Shuttle (IMPS)
	2823	Charge Control System
63707F		
2688	*WEATHER SYSTEMS (ADVANCED DEV.) BATTLEFIELD WEATHER SYSTEMS*	
	2781	Next Generation Weather Radar

65502F SBIR *SMALL BUSINESS INNOVATION RESEARCH*

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1) U.S. Air Force
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   - Ballistic Missile Office
   - Air Force Weapons Laboratory
   - Air Weather Service
   - Electronic Systems Division

2) Defense Advanced Research Projects Agency

3) Defense Mapping Agency

4) Defense Nuclear Agency

5) Defense Communications Agency

6) Department of Energy

7) National Aeronautics and Space Administration

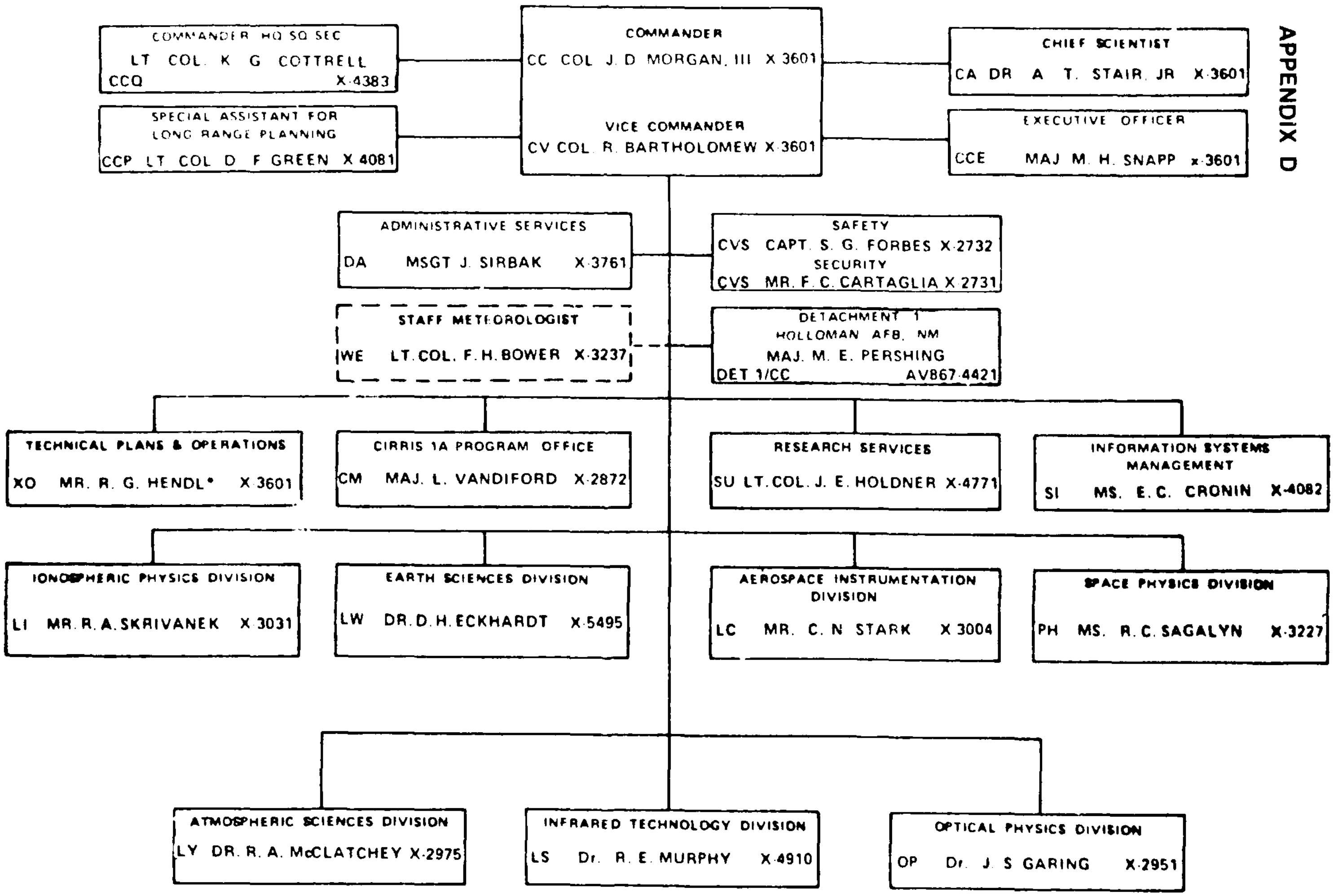
8) Navy

9) Army

APPENDIX D

Air Force Geophysics Laboratory

HANSCOM AIR FORCE BASE, BEDFORD, MASS.



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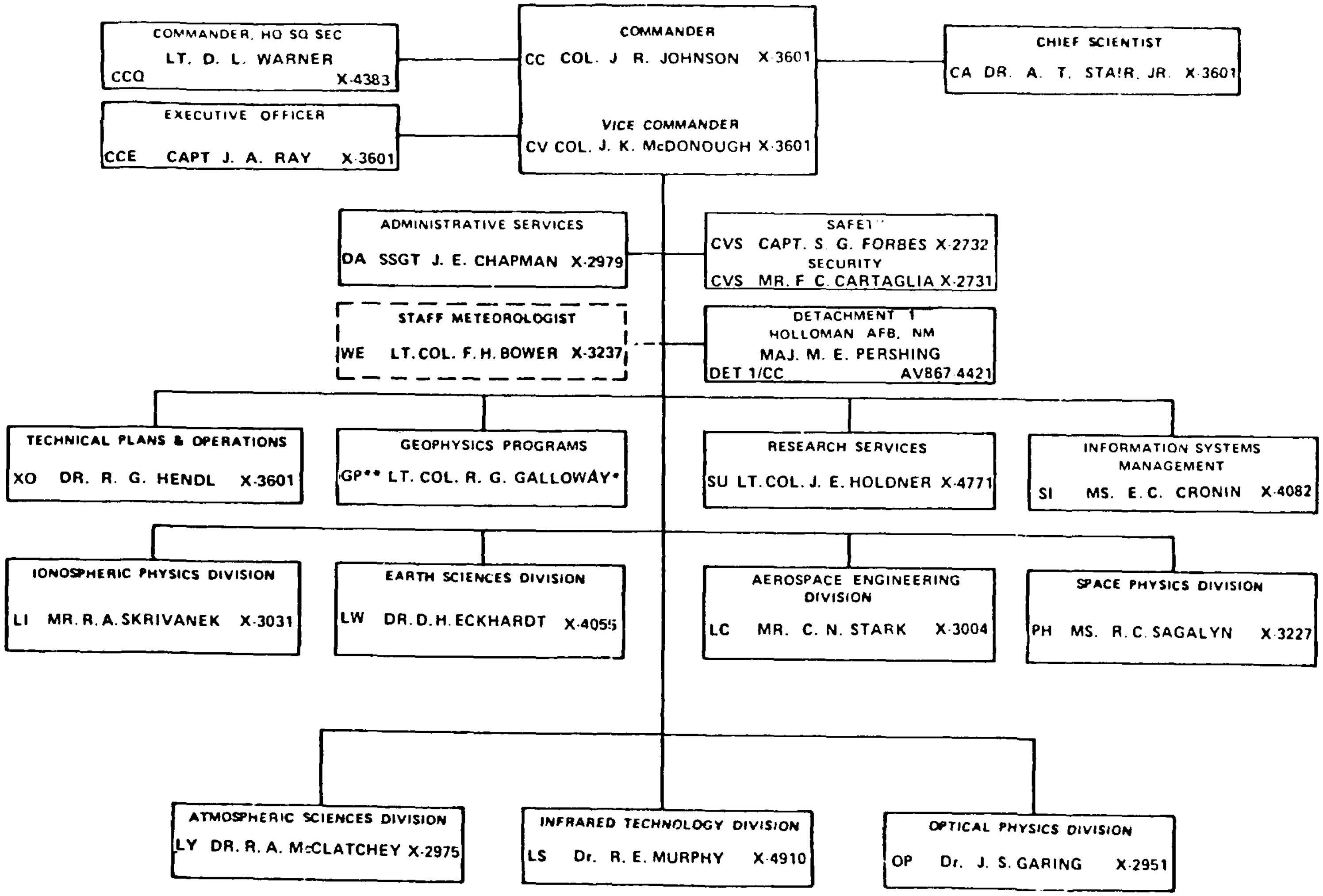
Commercial — Area Code (617) 861-XXXX

As of 1 January 1985
* Acting

Air Force Geophysics Laboratory

HANSCOM AIR FORCE BASE, BEDFORD, MASS.



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As of 1 August 1985
* Acting
** Pending MET-33 Approval