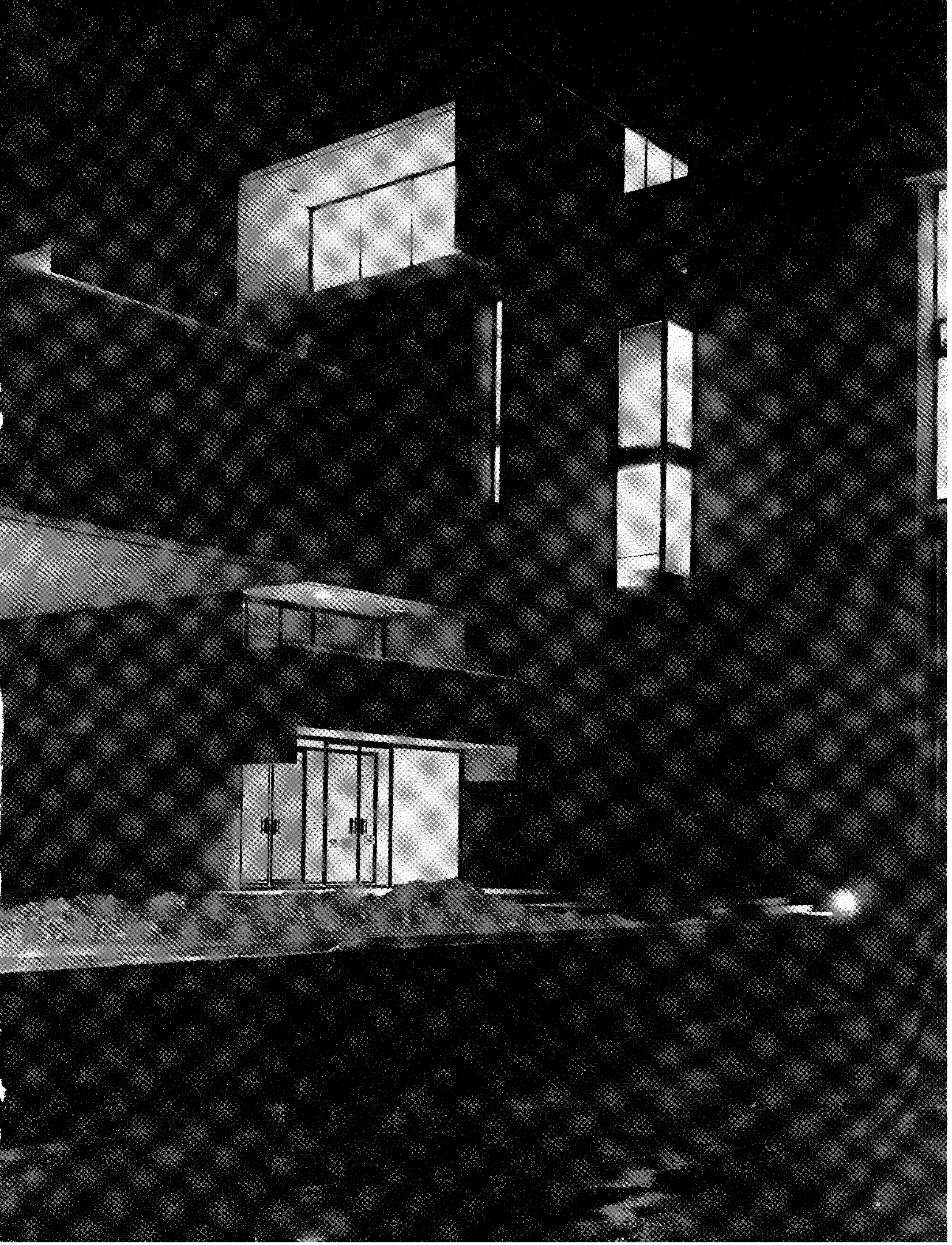
Annual Report
NCAR
Research and Facilities Programs

1966

National Center for Atmospheric Research

Boulder, Colorado

April 1967



FOREWORD

Annual reports of scientific laboratories differ enormously in style and in content. Ours has been intended for our scientific colleagues, and considered primarily a document for inside-NCAR communications, serving as an initiator of scientific conversations and collaborations and, for new members of our staff, as an orientation guide.

Past annual reports have also, we are told, served as quick-reference volumes for scientists elsewhere, through which they can determine whether something we are doing is intimately connected with any of their own research goals. The Annual Report has, in addition, proven to be a document that tells a scientific visitor, or perhaps a prospective visitor, what research efforts are in progress here, large or small, under whose stimuli they are being carried out, how far along they are, and who is doing what.

In this Foreword, I shall give a rather personal and non-specialized overview of NCAR-1966 -- intended for someone who may not want to look into more than a few, if any, of the detailed summaries that make up the main text of the Report. But since the Annual Report is primarily an internal planning and communications document, written in differing styles in different sections, it nonetheless remains something of an informal status report, rather than a formal publication of research results.

A BRIEF HISTORICAL PERSPECTIVE

NCAR traces its origins to, among other things, a series of studies by the Committee on Atmospheric Sciences (formerly the Committee on Meteorology) of the National Academy of Sciences (NAS). NCAR was shaped, in concept, by many distinguished members of those committees and their ad hoc study conferences. The distinguished mathematician and Atomic Energy Commissioner, John von Neumann, was one spiritual godfather -- through service on the Committee and also through the work he did to interest people in creating an institute for theoretical geophysics. The pioneer in atmospheric sciences, Carl-Gustav Rossby, was another member of the Committee with a great interest in the NCAR concept. The first specific NAS formulation of the recommendation for NCAR, so far as I am aware, came from the so-called Berkner Report of the NAS Committee, in January 1958, and its findings regarding NCAR were endorsed by the Council of the AMS, the President's Science Advisor, the Chief of the U. S. Weather Bureau, and by many other private and public groups.

Seventeen research planning conference groups were organized by Thomas F. Malone, William S. von Arx, and Roscoe R. Braham, Jr., all of whom played major roles in shaping NCAR's creation. These planning groups met and hammered out the details of a concept for a national institute, and these deliberations culminated in a major report transmitted to the National Science Foundation (NSF).

The upshot of all this was the invitation to me, in early spring of 1960, to join UCAR as its chief executive officer and as Director of NCAR. Soon after came the action of NSF, in June 1960, financing the creation of NCAR through a contract with the University Corporation for Atmospheric Research, a non-profit corporation, with the fourteen university members, and incorporated in Delaware. Each University named an administrative and a scientific Trustee to manage UCAR and its laboratory, NCAR. The Trustees were further empowered to elect a small number of additional Trustees-at-Large, to represent broad national interests. Dr. Lloyd V. Berkner of the Graduate Research Center in Dallas and Dr. Detlev W. Bronk, Rockefeller Institute, were named Trustees-at-Large in the early corporate history. The first chairman was Professor Henry G. Houghton, Massachusetts Institute of Technology -- who has given long and devoted service to UCAR and to NCAR. He was succeeded by Dr. Horace R. Byers, then of the University of Chicago, now Dean of Geosciences of Texas A & M. Dr. A. Richard Kassander, Institute of Atmospheric Physics, University of Arizona, now chairman, is the third to hold this post.

A second stream of activity contributed to the present character of NCAR. It was the High Altitude Observatory. The HAO traces its roots to the Climax Observing Station of the Harvard College Observatory, created in July 1940 by Professor Donald H. Menzel of Harvard University. As a graduate student, I became the first operator of the station. In April 1946 the HAO was incorporated as a Colorado corporation, with Trustees nominated by Harvard University and the University of Colorado. Judge William S. Jackson, then Chief Justice of the Colorado Supreme Court, was for years the president of the HAO, and he has served continuously from that day to this; he is now a UCAR Trustee emeritus.

Shortly after the founding of NCAR, the Delaware corporation was dissolved, and the High Altitude Observatory was reorganized as the University Corporation for Atmospheric Research (of Colorado) to which the former UCAR of Delaware transferred its contracts, activities, assets, and its corporate pattern of management. All of the Trustees of the earlier HAO have now served UCAR as Trustees-at-Large save for John L. J. Hart, who became UCAR's general counsel at the establishment of UCAR of Colorado. All of HAO's resources, of course, came along, including research facilities and real property, much of it acquired with private funding.

Today UCAR has twenty-three member universities, and several additional institutions are expected to join UCAR in the next few years.

NCAR'S RESEARCH INTERESTS

The atmospheric sciences in NCAR's definition, deal with the gaseous medium that begins at the earth's surface, and extends continuously outward till it merges with the atmospheres of the sun, the planets, and the most distant stars. Thus our research embraces the solar corona, the atmosphere of Jupiter and the earth's ionosphere, as well as the lower layers of the atmosphere, which we must breathe, fly in, get rain from, and within which we often must struggle to survive violent extremes of atmospheric behavior.

The range of our interests embraces such things as:

1. The gaseous trace constituents of the atmosphere, their origins in natural and man-made sources, including pollution processes, and the effect of these on the atmosphere.

2. Research on smoke, dust, and other solid air contaminants of natural or artificial origin; and their effects in droplet condensation, freezing of ice particles, and their role in atmospheric radiation balance -- and thus in making and changing climate.

3. The development of computers and models for experiments in atmospheric simulation on the global and continental scales -- with consequences for long-range forecasting and large-scale weather and climate modification research.

4. Influences of astrophysical origin upon the atmosphere, including solar effects in geomagnetism, ionospheric physics and interplanetary space physics.

5. Progress in fundamental mathematical, physical and other disciplines where major bottlenecks stand in the way of progress in atmospheric science -- as in the development of a better understanding of turbulence and of precipitation processes.

6. Work in the development and engineering of facilities, instruments, sensors and observing systems to meet difficult and critical problems of atmospheric science, such as the development of globe-circling horizontal balloons and in our work to upgrade the speed and capacity of computers for atmospheric problems.

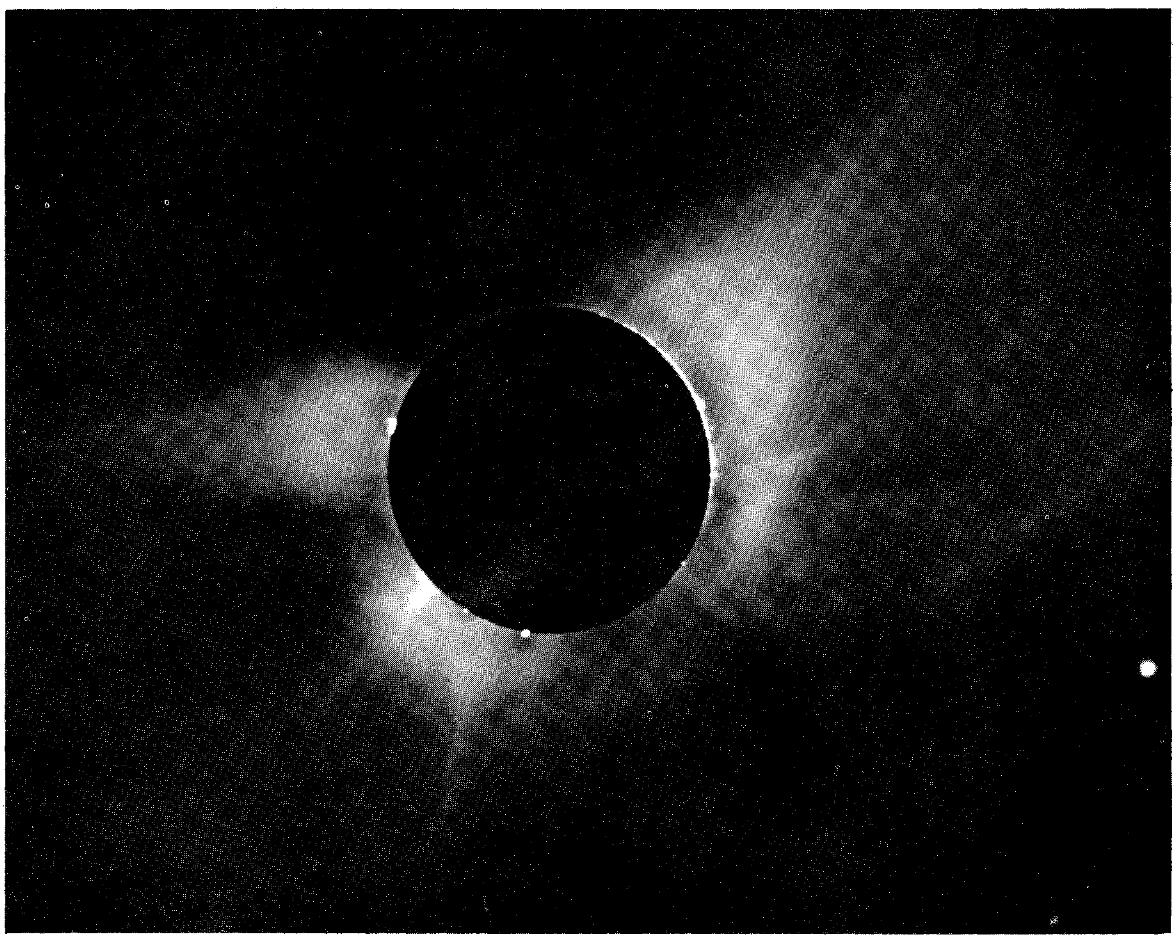
In pursuit of these goals we have created, in addition to our operations in Boulder, observing or facilities operations at sites in Climax, Colorado; Mauna Loa, Hawaii; Christchurch, New Zealand; and Palestine, Texas.

RECENT RESEARCH HIGHLIGHTS

1. Coronal research

On the High Altitude Observatory's expedition to the total solar eclipse at Pulacayo, Bolivia (on 12 November 1966), Gordon A. Newkirk, Jr. took the photo of the white-light corona of the sun shown here. It is an example of a novel technique used with striking success.

The sun's corona has long been mysterious. It is highly tenuous, with spectral lines of the highest ionization temperatures known appearing in the same regions of the solar image with perfectly modest and respectable stellar surface black body temperatures. In 1947, two distinguished astronomers, C. W. Allen and H. van de Hulst, working independently, proved quite conclusively that the sun's corona is made up of three superposed components of totally different physical cause; but there are still many problems to unravel before we understand the corona's effects on the earth's atmosphere. We see in Newkirk's photo the so-called "white-light corona," a composite principally of scattered light from two of the three coronal components -- electron scatter and interplanetary dust scatter.



Newkirk's photo was taken through a graded filter whose transmission was tapered to oppose the average fall in brightness of the white-light corona with distance from the sun. The bright and dark patches, streamers and arches are seen here as they appear to the eye at eclipse, but as rarely revealed in a single photograph. Usually such detail is visible only in laboriously reconstructed drawings made from series of eclipse photos of graduated exposure.

The structure seen in the photograph results almost entirely from irregularities in the electron distribution in the solar atmosphere, which are intimately involved with the magnetic field structure of the solar atmosphere. The arches and gaps seen near the sun's edge are probably phenomena of the magnetic fields of a sunspot region, and it has been suggested that they may be akin to what we find in the terrestrial "trapped radiation" associated with the Van Allen belts. These structural features are no doubt related to the X-ray emission, the solar wind, and the emission of charged solar particles, all of which have attendant ionospheric, auroral, and geomagnetic consequences. The solar corpuscular emission may perhaps also influence stratospheric pressure patterns in a significant way on some occasions, a matter to which my own personal research interest has been directed for the past decade and a half.

2. Atmospheric oxygen reactions with methane and sulfur dioxide

Richard D. Cadle, of the Laboratory of Atmospheric Sciences, has been working with his colleague Eric R. Allen and with a visitor from Ripon College, Dr. Jack Powers, on atomic oxygen reactions with methane and sulfur dioxide. The photograph shows a more recent apparatus similar to that used by Powers, Cadle and Allen, with Miss Janet Mehollin at work on it. Miss Mehollin is a cooperative undergraduate chemistry student from Beloit College working at NCAR this year.

Sulfur dioxide (SO_2) and methane (CH_4) have long been known to be trace constituents of the atmosphere. Nicolet, for example, assumed some years ago that methane existed in fair abundance even in the mesosphere at 90-km height, and that it was a major source of H_2 in the upper atmosphere. But the rates of reaction of these trace gases with atomic oxygen were unknown. Cadle and colleagues built the apparatus shown, and used it to do some fascinating gaseous continuous-flow "titrations" with microwave excited glow discharges, in partial vacua corresponding to various atmospheric levels. Their results establish that atomic oxygen rapidly reacts with methane above 40 km, and quickly destroys it. If concentrations of atomic oxygen in this region are as high as many scientists believe, this finding invalidates Nicolet's notion of methane as an important source of H_2 at upper levels.

Similarly, Cadle and colleagues, in work on sulfur dioxide, demonstrated that fast reactions with oxygen exist that are sufficient to give as a product SO_3, which in turn can react to produce sulfates, thereby giving substance to the idea that gaseous chemical reactions such as this produce the solid ammonium sulfate particles that were found at about 20 km by Christian Junge in world-wide surveys a few years back.

Incidentally, these reactions and others similar to them are of genuine importance in photochemical smog formation, and are under study at NCAR, with such matters in mind. The apparatus shown in the photograph, for example, has been used in recent experiments involving rates for the reactions of atomic oxygen with aldehydes. These are reactions which produce some of the unpleasant substances in such smog.

3. Raindrop coalescence

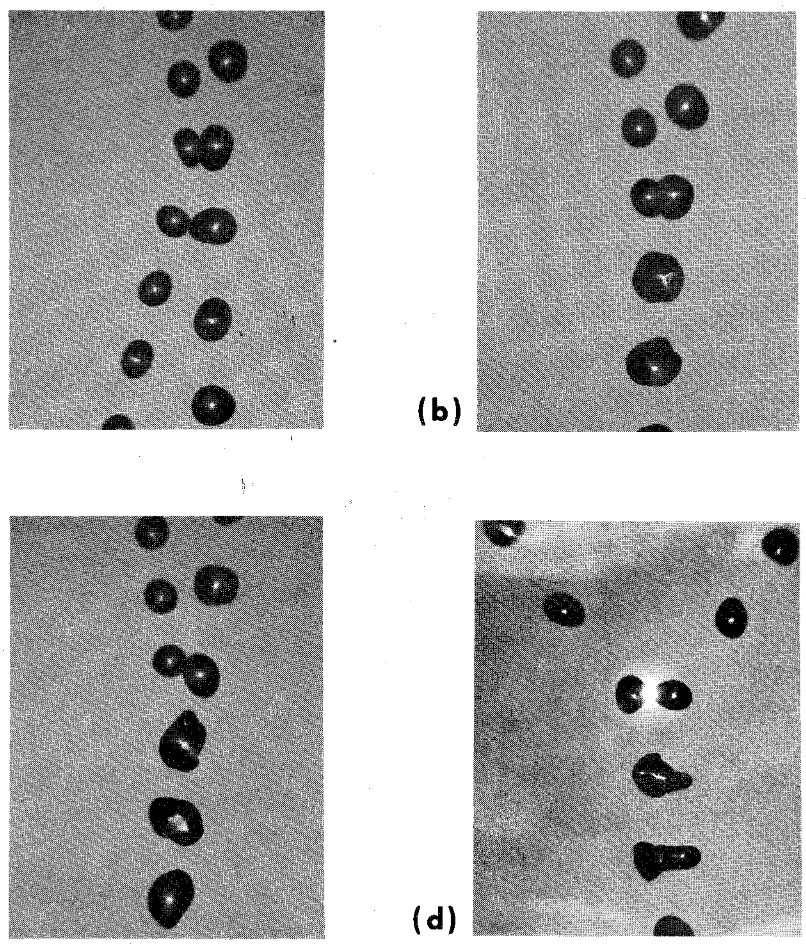
In the NCAR Laboratory we have a 35-foot high artificial cloud and raindrop shaft in which we plan several years of work to study electrification processes in clouds and the effect of cloud and raindrop electrification in droplet collision and coalescence, in a program conducted by J. Doyne Sartor and his colleagues. The photos that follow show droplets of similar size exhibiting various kinds of behavior: (a) drops uncharged and in absence of electric field are bouncing apart after collision; (b) similar drops in strong electric field are coalescing; (c) drops with opposite charges in absence of electric field are coalescing; (d) coalescing drops, when highly charged, discharge, giving off light as shown and electromagnetic radiation that is indistinguishable from true thermal emission in the UHF and microwave region. With such a mechanism terrestrial thunderstorms could appear 117^{o}K warmer at UHF, and the observed microwave temperature of Venus could be explained by clouds of charged particles colliding and radiating in this manner.

In the new shaft, not yet fully instrumented, we will simulate more realistically the process by which an embryo raindrop scavenges the million or so other cloud droplets necessary to form a typical rainstorm drop over the Central United States. One can easily visualize the fields of weather modification research to which this work relates.

4. General circulation research

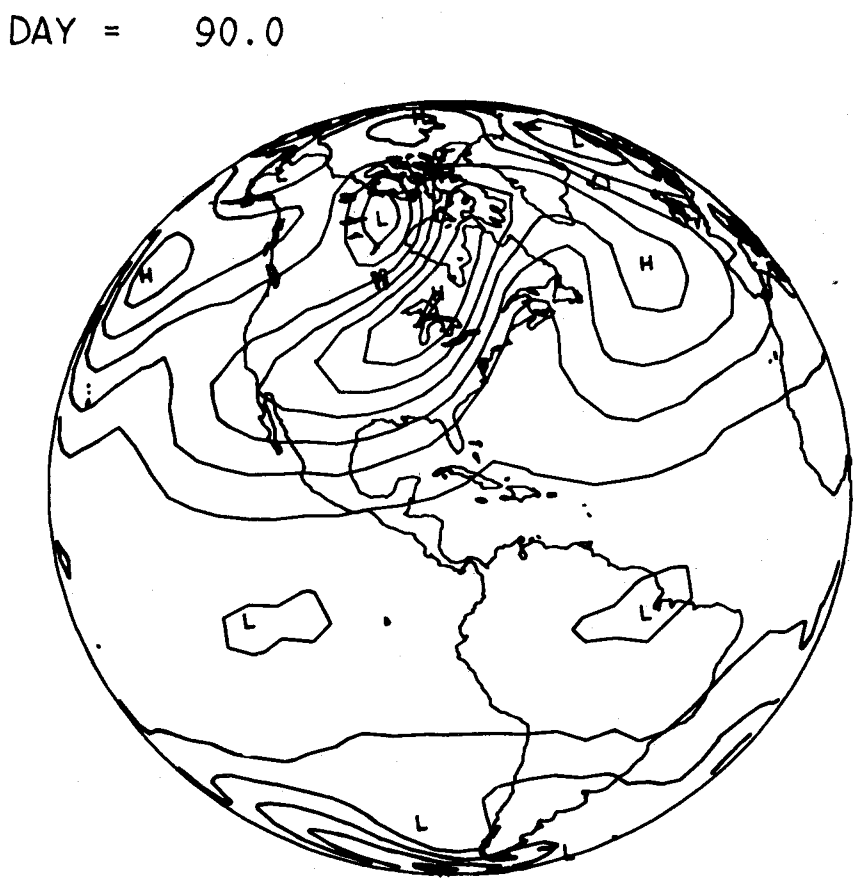
The largest group effort in the LAS in now focused on the development of an adequate theory of the general circulation. This is an ambitious task, and its dimensions are of course far beyond NCAR's capabilities, or even of U.S. capabilities, alone. Three parts of this task have been identified, and LAS and the NCAR Facilities Laboratory are working on aspects of all three. They are:

1. Numerical model development;
2. Super-computer development and acquisition; and
3. Global atmospheric measurement techniques.



(a) (b) (c) (d)

As Kellogg mentions in his report, below, Thompson has taken charge of the numerical modelling effort at NCAR, in a program that involves Kasahara, Lilly, Lindzen, Washington, Houghton, Deardorff and others. Their goal is to put together a realistic numerical model of the global circulation that can be expeditiously run on a fast computer, and to use it for experiments on various approaches to a successful theory of the general circulation. Our first simple model is running, and the first results are now coming forth. Our success thus far is due in no minor way to the excellence of our Control Data 6600 computer as operated by the NCAR Computing Facility. The model has two layers in the vertical, with 5^{o} intervals of latitude and longitude and five-minute time intervals for stepwise integration. Integrations are routinely run for hundreds of days. The results print out on 35-mm film from the Control Data 6600 through a Data Display model 80 machine, and can be shown as movies. The photograph shows a single frame from a computer-produced motion picture sequence of surface pressure distribution of completely computer-generated "weather." By fall we plan to have a six-level model running and real weather data used to specify the initial state, including theoretical analyses of southern hemisphere patterns and horizontal balloon (our own GHOST and the French EOLE) trajectories, which have already improved our knowledge of southern hemisphere circulations.



Success with realistic numerical models is a goal of profound importance in atmospheric science. To my mind it is the principal hope for success in long-range forecasting. But even more important, it is the only safe way I know of to try out global-scale or regional-scale weather and climate modification schemes without hazard to mankind. Therefore the development of realistic numerical models is clearly a central scientific goal of NCAR, and also merits the best possible effort by, and support for, the other groups in the United States that are striving for similar goals. There are so many important numerical experiments to perform, and the social and economic stakes are so great, that it is highly unlikely that undesirable duplication of facilities or experiments will occur in the foreseeable future.

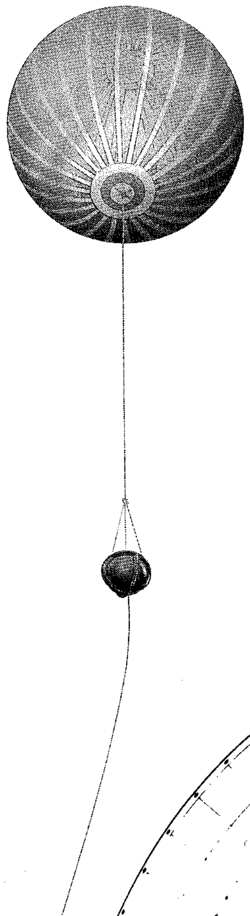
5. Pollution of the air

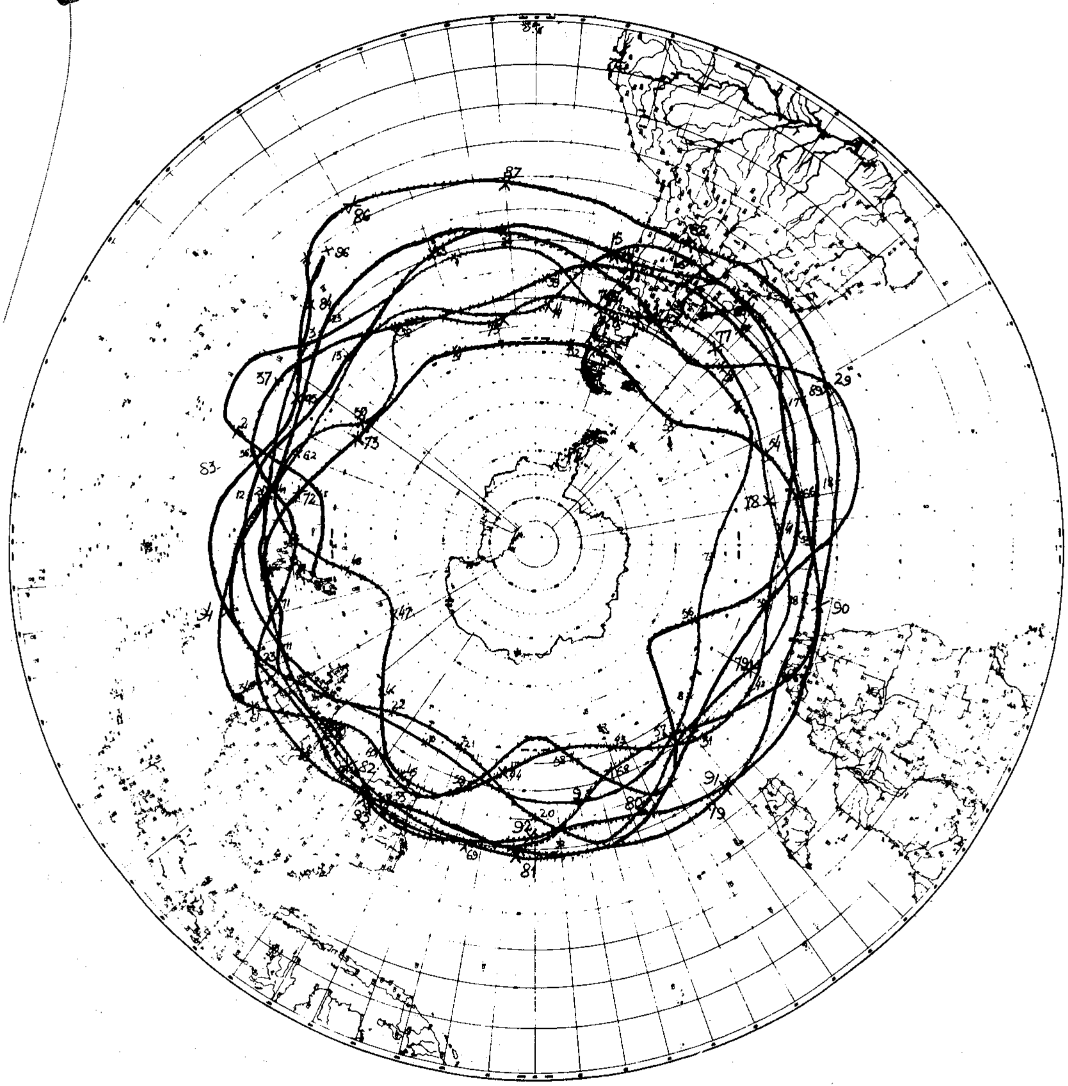
The practical need for air pollution control is seen everywhere in the United States and the world. NCAR is not vectoring its work toward air pollution research; but air pollution is so intimately tied up with the whole of atmospheric research -- dynamics, chemistry, radiation balance, etc., -- that much of what we do is of highest relevance to air conservation.

The site of our new NCAR Laboratory on its striking mesa affords spectacular visual evidence of pollution phenomena in the inversions below, extending all the way from Fort Collins to Denver. It is difficult to see this going every day without wanting to become involved in its cure. Lodge, Cadle and Goetz of LAS, are interested in various aspects of smogs and gaseous waste chemistry. Sartor has obtained some rather striking time-lapse motion picture sequences of the pollution in the Boulder air shed under various local wind circumstances.

6. GHOST balloon development

V. E. Lally's GHOST balloon program, carved out jointly with ESSA and the government of New Zealand (with the sponsorship of the World Meteorological Organization) has been dramatically successful. For example, one balloon, launched by Ernest Lichfield from Christchurch, New Zealand, on 28 April 1966, rose to the 45,000-foot level (200 mb), where it circuited the southern hemisphere every eleven to twelve days, beeping its positions from a three-ounce radio transmitter whose signals were consistently received at distances of up to 5,000





miles. During the night of 4 November, after 192 days in the air, the balloon fell into the South Atlantic, after giving us almost complete daytime radio reports of its trips around the globe. The accompanying photographs show a GHOST balloon, and a portion of the trajectory of the 28 April - 4 November balloon.

About thirty GHOST balloons have now successfully flown. One has flown 234 days and another 207. Still another has flown at 90,000 feet (30 mb) and at this writing has orbited twice from east to west in 52 days and started its third orbit. At this writing, seventeen balloons are in the air.

The significance of the GHOST system is easy to see. We have for the first time demonstrated a feasible global wind-sensing technique that gives realism to the hope for gathering complete wind-field data from upper levels over the entire earth, a prerequisite for the weather research and prediction systems of the future. And as a by-product, we have already significantly expanded the knowledge of the upper-level circulations of the southern hemisphere. Complete machine-analyzed trajectory data will soon be published from the first year of the GHOST program.

THE GLOBAL ATMOSPHERIC RESEARCH PROGRAM

There is a common goal behind NCAR's efforts in the numerical model, super-computer and GHOST programs. This goal is to develop an understanding of the global circulation that will permit improved long-range forecasting of weather, and specific numerical experiments in global-scale weather modification. The goal is not simply NCAR's, however. It was clearly enunciated for the United States and the world in the recent "Charney Report" of the National Academy of Sciences Committee on Atmospheric Sciences. It is, moreover, now the subject of international planning efforts within the World Meteorological Organization and the International Council of Scientific Unions. The task is so great that it is sure to involve both the governments of the world and the nongovernmental scientific organizations.

The genesis of this effort was a U.N. resolution on the peaceful uses of outer space, in 1961. Presidents Kennedy and Johnson have both indicated this country's strong interest in pursuing the goal of a world weather system for both operations and research.

During 1966 the ICSU/IUGG Committee on Atmospheric Sciences designated the 1970s as the target date for a first real-life global weather research and observing program, to which they gave the tentative name of the Global Atmospheric Research Program (GARP). It will involve truly global data-taking, including research expeditions for intensive observations of a special nature; and it will require the full participation of a particularly intensive nature by the governments of the world organized under the WMO-based World Weather Watch. It will likely be an IGY-like special period of six months to a year, during which data will be gathered for subsequent research on the general circulation. Some of us feel this may also be a realistic prototype of the ultimate world weather observing system. Best present estimates are that this program can be brought about by 1975-76.

Jule Charney has called the program for global observation "the great leap" that must be taken for us to know with assurance how far we can go in long-range weather forecasting or large-scale weather modification.

Associated with GARP must be a series of prerequisite research projects designed to specify the details of GARP itself. For example, it will take a series of intensive tropical investigations to determine the scale of weather data required to define the moisture and heat supplied to the atmosphere of the tropics, which is in turn essential to understanding the energetics of the higher latitudes. By the early 1970s, there should be a major tropical area study -- sometimes termed TROMEX -- in the vicinity of the Marshall Islands. Though a pilot operation compared to GARP itself, the tropical experiment will nonetheless be a major international effort.

NCAR sees for itself a major role in the pursuit of GARP and its precursors. First of all will be NCAR's direct research and development commitments, evident in the discussion of NCAR research earlier in this Foreword. NCAR stands ready to do at least these three additional things:

1. To serve as a rallying point and planning focus for the university community participation in GARP, which must be a major part of the U.S. effort;

2. To aid in organization and management of the logistics for joint NCAR-university activity in GARP; and

3. To promote the necessary and major participation of the governmental agencies and laboratories in the research and its logistics.

NCAR is deeply involved in managing the Line Islands Experiment, now under way. Nine universities (counting Woods Hole Oceanographic Institution) and ten federal agencies are participating, in addition to NCAR. The Experiment has promise of highly effective exploitation of the ATS-1 synchronous satellite that sits, carrying Dr. Verner Suomi's spectacularly successful camera, some 22,000 miles above the Line Islands, where it gives, upon command, pictures of the cloud cover at 20-minute intervals. The Experiment promises, if successful, to help define requirements for the tropical experiments tentatively planned for 1972.

It is clear that the Line Islands Experiment would not have been mounted, nor would the participating universities and governmental agencies be involved, had not NCAR moved quickly to take up a complex planning and management effort on an exceedingly short timetable. Moreover, it could not have been accomplished had not NCAR been able and willing to reprogram major research funds, equipment and staff, and had not NSF been able on short lead time to add further funds to the logistic support.

The ability to mount this kind of effort is one of the attributes the university community and the NSF had in mind for NCAR when it was brought into being. It is, indeed, our first mettle-testing in an effort of this magnitude and difficulty. Success in the Line Islands program has not yet been assured. Nonetheless, NCAR's solid response of manpower and material resources has evoked similar responses in other organizations. As a result, precedents will have been set, and experience will have been gained that will be of great value as we proceed toward GARP.

CONCLUSION

GARP is perhaps the largest challenge for us ahead. But there are others. If I were to name a problem that will be hardest for NCAR to manage, as I see the future, it would be the problem of how to respond in the ultimately most beneficial way to the pressures on NCAR generated by the extraordinary social needs for the products of research in the atmospheric sciences. These pressures show up as forces directed toward too great growth in the size of NCAR, and in temptations toward picking up commitments to pursue research that is too narrowly aimed toward socially useful results.

We are confident that our partnership -- a partnership of NSF, the universities of UCAR, and the staff of NCAR -- gives us an almost ideal mechanism for a constructive and creative response to these forces. NCAR is reaching toward a level of scientific work that can interact in the most beneficial way with the universities. NCAR already has the spirit of freedom of research choice that must characterize a basic research center, but we are also appropriately and urgently motivated toward advancing the state of knowledge of what now appear to be the most critical and intractable problems in this highly intractable realm of science.

In short, NCAR's principal goal continues to be to make truly significant contributions to a greatly improved national atmospheric science effort.

Walter Orr Roberts

Walter Orr Roberts
Director

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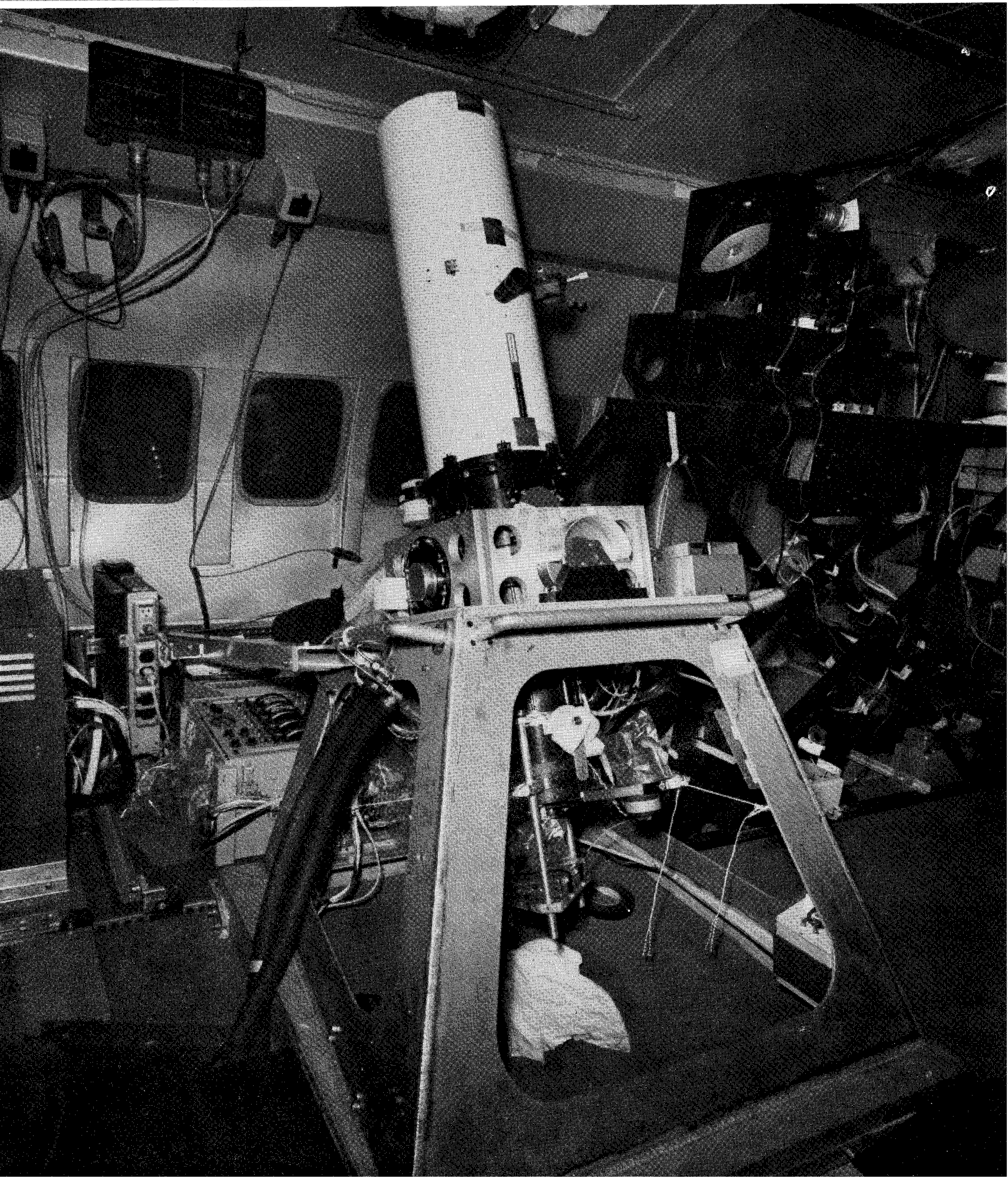
High Altitude Observatory



INTRODUCTION

Research at the High Altitude Observatory during 1966 progressed along much the same lines as in previous years. Most of our effort has been devoted to observing the corona in both white light and the light of various emission lines, observing and interpreting various manifestations of solar activity, refining and improving the theory of absorption line formation in the solar atmosphere, attempting to produce astrophysical effects in laboratory plasmas, and unraveling the complex measurements of geomagnetism and the ionosphere in order to understand the upper regions of the earth's atmosphere. In each of these areas we have made some progress.

In attempting to assemble definitive observations of the solar corona we usually find ourselves making severe compromises in order to observe at all the faint light of the corona against the much brighter sky light or instrumentally scattered light. The koronameter, now operating in its second year on the north slope of Mauna Loa in the Hawaiian Islands, can with some ease detect light from the corona arriving from one particular direction. However, to build up a picture of the corona from the edge of the sun out to one radius above the limb requires hours of observing and subsequent calibration, and in the process information on changes with time as well as on fine details of coronal structure are lost. In our attempt to build a coronagraph to fly on an earth-orbiting satellite, other types of compromises are being made. Here we have the possibility of seeing fine detail, but we must give up observations close to the edge of the sun in order to reduce instrumentally scattered light, and we are limited to the number of days of observation scheduled for the flight of the particular satellite on which the instrument will be flown.

Another set of compromises occurs when there is a total eclipse. During the year we attempted to make full use of the eclipse in South America on 12 November to gain a different view of the corona. Although the duration of an eclipse is only a few minutes, during those few minutes no problems of instrumentally scattered light arise, since no sun is in the field of view and the sky surrounding the sun is quite dark. The corona can be observed quickly and in its fine detail. In addition, exploratory experiments can be done during the eclipse with relative ease, and if successful they may lead to complex instruments to observe phenomena outside of eclipse. One of the greatest difficulties in eclipse observations, however, is that observations must be made on a rigid schedule in which no delays can be permitted. Preparations for the eclipse, therefore, assume the highest priority in our shops and for our staff, pushing aside other work of equal importance. Travel to and from the eclipse site is generally arduous and the no-second-chance atmosphere creates a psychological hazard for those actually operating the equipment.

As an organization, the High Altitude Observatory probably has as much experience as any in the world in conducting complex eclipse observations. Since 1952 we have attempted to observe seven eclipses, and to some of these we have sent multiple observing parties. In 1963 we had ten stations across Alaska, Canada, and the United States, and in 1966 we sent three groups and cooperated with a fourth. Even with all this experience each eclipse brings new problems, many at the last moment. We sometimes are ourselves surprised at the success of our observations.

This year was no exception. Our largest group, stationed in southern Bolivia, experienced expected difficulties of transportation, lost shipping crates, and primitive living conditions in establishing their observing site, but also had to contend with such problems as the lack of adequate maps of the area (so that the eclipse path itself was difficult to determine), and a last-minute equipment failure. However, the eclipse path was located with sufficient accuracy, heroic work on the equipment restored it to operation, and successful observations were made of both the white light and emission line corona.

In coastal Peru, one man from the High Altitude Observatory, working with colleagues from the Environmental Science Services Administration, secured observations of the earth's magnetic field near the eclipse path. There our planning and preparation were perhaps deficient, as observations of the magnetic field resulting from this work seem so strange we do not as yet have sufficient confidence of their reality to attempt an interpretation.

On the east coast of South America our equipment was placed in a jet aircraft and flown out over the south Atlantic. The aircraft gave us more than three minutes of totality and also gave us high probability of freedom from clouds. Airborne observation of eclipses was entirely new to us and necessitated our learning about gyrostabilized platforms and the modes of aircraft motion and vibration. But here, too, we obtained observations of the solar corona.

Another region almost as inaccessible as the solar corona is the earth's ionosphere and its boundaries with the magnetosphere and the upper atmosphere. This region can be probed by radar from earth, penetrated by rockets and satellites, and monitored by fluctuations in the earth's magnetic field. However, we have in this region a complex range of phenomena, being detected by an equally complex series of observations, without simple correspondence between the various facets of the two. Our problem here is the detailed unraveling of the various effects. If, for example, one has a number of geomagnetic monitoring stations sufficient to describe completely an ionospheric current system producing geomagnetic fluctuations, one is still left with problems of the height and source of origin of the current system. Winds in the ionosphere can be caused by tidal effects of the sun and the moon, and by a number of other forces. Ionization is not at all simple and the influence of the magnetosphere must be taken into account. Putting all of these factors together to produce a workable explanation of the current system remains a major problem. In this area, therefore, we search for a few simple factors which will help us unravel our observations and construct a suitable model.

John W. Firor
Director

THE CHROMOSPHERE

CHROMOSPHERIC MODELS AND THE H AND K PROBLEM

A basic problem studied vigorously at the High Altitude Observatory is that of interpreting observations of emission and absorption lines originating in the solar atmosphere. The intensities and profiles of such lines contain a wealth of information and, in principle, one should be able to deduce chemical abundances and many physical parameters of the solar atmosphere, if the line profiles can be interpreted. By their very nature, however, lines must originate in regions which are not in thermodynamic equilibrium; hence the interpretation of measurements of the lines in terms of other quantities is not at all straightforward. In previous years in these reports we have discussed the different aspects of our approach to the problem of interpreting observed line profiles and our effort to gain some insight from these profiles into the physical structure of the solar atmosphere.

The methodology for understanding the transfer of radiation of the solar atmosphere has been developed slowly over the years at the Observatory and other institutions. One must eventually master the details of absorption and emission of radiation by an atom in a radiation field characterized, not by a simple temperature, but by a much more elaborate (and initially unknown) distribution, and surrounded in addition by moving atoms, ions, and electrons whose velocities probably can be described by a temperature. So far, approximations must be made at every point in the calculation. Atoms are usually approximated by resonant systems with but two energy levels, for example, and the approach has usually been to integrate the radiative transfer equation through a model atmosphere, and to compare the predicted line intensity or some feature of the profile with observations. Work has been hampered by the lack of knowledge, in many cases, of the relevant atomic parameters, particularly collisional excitation cross sections.

A severe test of progress in this field has been the observed characteristics of the two strong Fraunhofer lines attributed to ionized calcium, the K and H lines. The profiles of these lines are complex in shape, and contain a small emission peak near the center of the absorption line; the emission peak itself contains an even narrower absorption feature near its center. Yet certain factors point to these lines as simple ones to study. Calcium can be considered an "impurity" in the solar atmosphere, so that the continuum radiation field is governed by other atomic species. Furthermore, the K and H lines are resonance lines, and current astrophysical evidence (observed line shapes) indicates that non-coherent resonance scattering (i.e., in which scattered frequency is not correlated to incident frequency) represents a sufficiently accurate approximation to the nature of line formation in stellar atmospheres. If one neglects fluorescent conversion, and the inverse process which is associated with the non-resonant states (i.e., subsidiary levels including the continuum), one obtains a two-level-atom description of the scattering processes.

Our study of the calcium K and H lines can be described in three progressive steps: (1) reformulation of the theory of spectral line formation, (2) testing of the new formulation on simplified solar models, and (3) an attempt to reproduce the observed profile.

1) Reformulation of the theory of spectral line formation, described in the 1965 Annual Report, has been continued with considerable success. Athay and Skumanich were able to produce a reformulation which has several advantages over older theories. Whereas older theories emphasize departures in the number of atoms in each possible energy state from the numbers that would exist in these states under a situation of thermodynamic equilibrium, the new formulation tries to emphasize the various possible processes needed to describe the transfer of radiation through the atmosphere. These processes are characterized by several param-

eters, each of which can be given a good physical definition. The first of these is a measure, ϵ, of the thermal coupling of the atom to the electron gas or the "local heat reservoir." This parameter is defined as the ratio of radiative to collisional lifetime of the excited state of the atom, and it can also be thought of as a measure of the strength of collisional generation of photons in units of the LTE value.

A second parameter, δ, measures the strength of the generation of photons by the continuum and is given by the ratio of continuous (LTE) emission coefficient to mean (LTE) line emission coefficient. Consequently the ratio δ/ϵ is equal to the ratio of the photon generation rate by continuous emission, integrated across the bandwidth of the line, to the generation rate by collisions with the electron gas. Thus this ratio indicates the nature of the source of the photons which are undergoing scattering. If $\delta > \epsilon$, then the continuum is the dominant source of photons; if $\delta < \epsilon$, the electron gas is the dominant source; and if $\delta \simeq \epsilon$, both are important.

Additional parameters which enter into the physics of line formation are the reciprocal line-strength, r_o, given by the ratio of continuous to line-center absorption coefficient, and the line absorption coefficient shape, which may be approximately parametrized (following the 1955 nomenclature of J. E. F. King) by a "greyness" number, Γ, which is the ratio of half-width to bandwidth. As might be expected from the above definition, δ is given once r_o and line-shape (or greyness) are given. A further parameter is the thermal gradient, β, of the atmosphere under consideration or, equivalently, the limb-darkening coefficient. This parameter, which represents the asymptotic deep atmosphere behavior of the line source function, measures the role of a third source of photons, the net flux upwelling from the deep interior. For $\beta = 0$ there is no upwelling net flux in the interior. That such a source is important is easily seen since in the case of pure scattering ($\epsilon = 0$), with no continuous source ($\delta = 0$), it is the only source of photons.

2) The second step in the development of a satisfactory theory for calcium H and K lines was the testing of the new formulation of the theory of spectral line formation on some simplified solar models. In this way we could become familiar with the influence of each of the parameters on the final line profile that should be observed from the particular model.

Numerical solutions based on the differential equation approach described in last year's report were obtained by Skumanich for a variety of values of ϵ, r_o, Γ and β. Since the continuum is assumed to be in LTE, the rate of generation of photons by continuous emission is a function of thermal stratification and does not enter as a separate degree of freedom. Simple variations were also considered in the above parameters.

For a thermal stratification which yields a linear Planck function and constant parameters, results indicate that when photon generation by the electron gas is unimportant compared to the other two sources (i.e., $\epsilon < \delta$ and $\epsilon < \beta r_o$), then the line radiation field (and hence the line source function) is controlled by either or both of the other sources. Thus, if $\delta > \beta r_o$, the surface value of the source function (and hence the central intensity of the absorption line) is approximately $\sqrt{\delta}\, B_o$ (B_o is the surface value of the Planck function). If $\delta < \beta r_o$, the central intensity is $\simeq \sqrt{\beta r_o}\, B_o$ (B_o is also a measure of the asymptotic upwelling flux). If the two sources are comparable, the central intensity is $\simeq \sqrt{\delta + \beta r_o}\, B_o$. If the electron gas source is more important (i.e., if $\epsilon > \delta$ and $\epsilon > \beta r_o$), then the central intensity is $\simeq \sqrt{\epsilon}\, B_o$, in agreement with the work of Jefferies and Thomas. In any case, the square-root law is related to the basic diffusive nature of the scattering process.

The depth variation of the line radiation field (line source function) can be described by a power law dependence regardless of the nature of the "source" over a large range of line-center depths. The exponent determined by the form of the line shape (i.e., by the greyness number), is 0.5 for a gaussian and 0.25 for a dispersion shape. In the case of a Voigt shape both power laws apply: in the upper layers, where the gaussian core dominates, the 0.5 law applies; below the line-center optical depth $\simeq \underline{a}^{-1}$ (or $\tau_c \simeq 1/\Gamma^2$) (where a is the damping constant) the dispersion wings dominate and the 0.25 law applies.

The final property of the line radiation field is given by the depth, Λ, at which it saturates to equilibrium with the driving "sources," i.e., the depth of the boundary layer. This depth, as one might surmise from the above, depends upon the greyness number. If the electron gas coupling is weak (i.e., $\epsilon < \delta$), then the saturation distance (a generalization of the thermalization length of Jefferies) is governed by δ. The saturation distance at line center is found to be δ^{-1} for a gaussian, $\underline{a}\delta^{-2}$ for a Voigt, and δ^{-2} for a pure dispersion shape. Where the ϵ-coupling is dominant, the same formulas hold, in agreement with the earlier work of Jefferies and Avrett and Hummer.

Skumanich finds that the spatial properties of the line radiation field are thus governed by the greyness number or line shape, regardless of the nature of the "source." As others have shown, the greyness number affects the photon escape probability and hence the number of scatterings before escape through the wings. This affects the spatial rate with which the line field builds up to its saturation value.

Numerical analysis of the case $\delta = 0$, $\beta' = \lim_{r_o \to 0} \beta r_o \neq 0$ and $\epsilon \neq 0$ shows that the line radiation field is controlled by β' for $1 > \beta' > \epsilon$. This case applies for an atmosphere with only the upwell net flux and the electron gas as "sources." The central intensity is $\simeq \sqrt{\beta'} B_o$. For $\epsilon > \beta'$ one obtains the usual $\sqrt{\epsilon}\, B_o$. It must be mentioned that the bandwidth of the line shape must be restricted in this problem. If it is not, then the condition $\phi(\Gamma^{-1}) \simeq \epsilon$ determines the bandwidth; if $\epsilon \to 0$ the bandwidth becomes infinite (zero greyness), with singular results. If the bandwidth is physically restricted then $\epsilon \to 0$ leads to the simplest of line transfer problems, namely, pure scattering whose solution was given by J. I. King in 1954. In King's example, β' governs the surface value of the line source function ($\sqrt{\beta'}$ law), while the spatial properties are governed by the greyness number, Γ. The above problem with $\epsilon \neq 0$ is a generalization of King's analysis.

The effect of height variations in these parameters was next studied. The one additional parameter whose role was not clarified above is that of the bandwidth of the line. In the above analysis only the ratio of half-width to bandwidth appears. The "absolute" value of the bandwidth never enters.

Skumanich studied the role of this parameter by allowing an arbitrary variation of the line half-width but keeping the other parameter (ϵ, r_o, Γ, β). (Since Γ = constant, this forces an equivalent variation in bandwidth.) The width was allowed to increase or decrease inward (as described in the 1965 Annual Report). It was found that when the width increased (decreased) inward, the line radiation field was depressed (elevated) compared to the constant width value. Thus in a chromospheric example with $\epsilon = 10^{-4} = r_o$, $\Gamma \simeq 1$, $\beta = 1.5$ one finds that the source function is increased by 20% when the width decreased by a factor of 1.6 through the atmosphere. This result may be understood as follows. The decrease in bandwidth represents a relative reduction in diffusion and escape through the wings, causing the line radiation field (source function) to build up to higher values. The opposite occurs for an increasing width.

With the introduction of an idealized chromosphere (i.e., a hot outer shell) superposed on a cooler normal photosphere (defined by β), two additional parameters enter into the line formation analysis. As indicated in the 1965 Annual Report, these are the optical thickness at line center of the outer shell, τ_e, and the shell temperature, T_{max} (alternatively, the ratio A of the Planck function in the shell to that at the photosphere). By adding a simple exponential decrease for the Planck function through the chromosphere to the linear photospheric Planck function, one can show that τ_e is given by the optical distance over which the "chromospheric" temperature falls to e^{-1} its surface value. In terms of the continuum "thickness" of the chromosphere $\tilde{\tau}_c$, $\tau_e = \frac{1}{r_o}\tilde{\tau}_c$.

Numerical analysis with this simple chromospheric model has been continued this year and is essentially complete. Basic results are as follows: The measure of the contribution of the chromosphere to the line radiation (source function) is governed by its optical thickness, measured in units of the saturation length $\Lambda(\epsilon, \delta)$. If the chromosphere is very thick (i.e., $\tau_e/\Lambda > 1$), the line radiation field saturates before one passes through the chromosphere, and one obtains an emergent emission line with a central reversal given by $\sqrt{\epsilon + \delta}$ A and a peak sitting A times above the photospheric continuum. Its half-width, y, in units of the shape half-width, is roughly given by $\phi(y^*) \simeq 1/\epsilon$ if ϵ-dominated, or $1/r_o$ if δ-dominated.

If, at the other extreme, the chromosphere is thin ($\tau_e < 1$), then the contribution to the line radiation is roughly that of adding the quantity $(\epsilon + \delta)$ A to the surface value, with a width determined by the thickness of the chromosphere.

The more interesting intermediate case is with $\Lambda(\epsilon, \delta) > \tau_e > 1$, or, in the Avrett-Hummer nomenclature, the "effective" thin case. Skumanich finds that, in this case, since the chromosphere is thick ($\tau_e > 1$) and multiple scattering is important, the line radiation field in the chromosphere (hence the source function) begins to suffer build-up: it begins to rise above the thin value $(\epsilon + \delta)$ A and approach the saturated value $\sqrt{\epsilon + \delta}$ A. The location of this build-up or peak in the source function occurs approximately at $\tau \simeq \tau_e$ with a slight dependence on ϵ, and, for $\tau_e > \underline{a}^{-1}$, on the damping constant $\underline{a}$ (cf. 1965 Annual Report). Thus it is τ_e, the optical thickness (at the center of the line) of the chromosphere, that fixes the location of the emission reversal. It is in the nature of the dependence on ϵ and $\underline{a}$ and the inclusion of a variable width that this result differs from that of Jefferies and Thomas.

The intensity of the emission reversal (the magnitude of the build-up or the peak in the line source function) depends upon the strength of the local sources, namely $(\epsilon + \delta)$ A, and on the optical thickness τ_e. In the case that $\tau_e < \underline{a}^{-1}$ (the doppler-equivalent case, see above), Skumanich finds that the line radiation field is $\simeq 2\tau_e(\epsilon + \delta)$ A. It is evident from this result that changes in the chemical abundance of calcium which lead to a "weaker" line strength (i.e. a larger value of r_o and hence, δ), lead also to an enhancement of the reversal intensity. This is a possible explanation for the presence of emission in the sub-dwarf Groombridge 1830 (calcium is underabundant by a factor of 10^2, i.e., δ is larger by 10^2), which, being an old star, should have no emission reversal. We would say that this star is continuum-source dominated (δ-dominated) rather than collision-source dominated (ϵ-dominated). The dispersion-equivalent case, in which $\tau_e > \underline{a}^{-1}$, is still under analysis; preliminary results suggest that the peak is lowered, i.e., the build-up is reduced due to enhanced photon escape in the wings. The build-up appears to be $2\sqrt{(\tau_e/\underline{a})}$ $(\epsilon + \delta)$ A.

The effect of variable width, which represents the basic difference between this work and that of Jefferies and Thomas, was more pronounced on the computed emergent field than on the internal field. This is due to the direct influence of the width on the depth to which one "sees." However, it was found that one could interpret the constant width profiles, apart from intensity changes, by considering that the unspecified width (in the constant width case) is given by the width at the depth of formation of the reversal (i.e., of the scattering build-up), or roughly, at unit optical depth in the line center.

3) The third stage in the development of an H and K line theory was, of course, to attempt to reproduce the observed profile of the solar H and K line. The first step in such a process is to develop practical methods of handling the numbers involved.

The approach here was to use the integral reformulation of Athay and Skumanich. This reformulation differs from other approaches in that it makes use of a different form of the radiative transfer equation. The approach has distinct advantages over previous methods in both versatility and stability. In particular, the effects of the various atomic and atmospheric parameters on the resultant solutions are clearly discernible from the basic equation, and all parameters may be varied through the atmosphere without unduly complicating the numerical solutions.

For a spectral line in which interlocking may be neglected, the total source function at point y in frequency may be expressed in the form

$$S_\zeta^T = B + \frac{\phi_\zeta}{\phi_\zeta + r_o}\,\frac{2}{\epsilon+\delta}\,\frac{1}{\sqrt{\pi}}\int_o^\infty \frac{\phi_\zeta}{\phi_\zeta + r_o}\,\frac{dH_y}{d\tau_o}\,dy \qquad (1)$$

where

$$y = \frac{\Delta\nu}{\Delta\nu_D^1}$$

$$\zeta = f(\tau_o)y$$

ϕ_ζ = absorption profile, which can be described by Γ, the greyness number

$$r_o = d\tau_c/d\tau_o$$

$$\delta = 2r_o \int_o^\infty \frac{\phi_\zeta}{\phi_\zeta + r_o}\,dy$$

$$\epsilon = C_{21}/A_{21}$$

and where

$$H_\zeta = \frac{1}{2}\int_{\tau_\zeta}^\infty S_\zeta^T E_2(t_\zeta - \tau_\zeta)\,dt_\zeta - \frac{1}{2}\int_o^{\tau_\zeta} S_\zeta^T E_2(\tau_\zeta - t_\zeta)\,dt_\zeta .$$

Solutions to Eq. (1) for prescribed values of B, ϵ, r_o, ϕ_y and $f(\tau_o)$ were first attempted by iterative methods. The methods tried proved to be unstable, with successive solutions diverging rather than converging. After it became clear that the equation was not well suited to an iterative solution, this approach was abandoned in favor of a direct solution utilizing sets of linear equations. Although this method appeared formidable at the outset, it turned out to be very practical and relatively simple. Programming for this approach was done by William Frye of the NCAR Computing Facility.

The basis of the method is to regard Eq. (1) as a matrix equation of the form

$$S_\zeta^T = (1+\alpha_\zeta)^{-1} B$$

where α_ζ is a matrix operator and S_ζ^T and B are vectors in τ space. To derive α_ζ we expand S_ζ^T at each point in y space in terms of a set of linear functions in τ_ζ. For n points in τ space and m points in y space, we have m sets of linear equations with n equations in each set. We then derive H_ζ in terms of these sets of equations and express the result in m matrices of order n x n. The m matrices are next differentiated numerically with respect to τ_o, then integrated with respect to y to form a single matrix that is simply related to α_ζ. Since m is of the order of 20 and n is of the order of 35, the program requires considerable machine storage. S_ζ^T is related to the line source function S by

$$S_\zeta^T = \frac{\phi_\zeta}{\phi_\zeta + r_o} S + \frac{r_o}{\phi_\zeta + r_o} B .$$

Thus S_ζ^T need be evaluated at only one value of ζ, and S is readily obtained.

This method of solving for S has distinct advantages. Solutions are unusually stable against changes in the τ grid and they are not particularly sensitive to the choice of the y grid so long as a sufficient number of y points is used. Reliable solutions for S with $\epsilon = r_o = 10^{-4}$ have been obtained with eight τ points and seven y points. The τ points were spaced at intervals of one decade between 10^{-2} and 10^{5}. The y points were chosen to give values of ϕ_ζ close to, but lying on either side of r_o, and to give values of y near line center.

One of the first problems investigated after a working code was perfected was the behavior of S near $\tau_c = 1$. Equation (1) is of a form that is well suited for this problem.

Deep in an atmosphere where $\tau_c > 1$, and where there are no sources or sinks of energy, $dH_\zeta/d\tau_o$ is zero and S = B. As soon as $\tau_c < 1$, $dH_\zeta/d\tau_o$ is no longer zero at large values of ζ, and S begins to differ from B. For B of the form

$$B = 1 + \beta\tau_c$$

the sign of $dH_\zeta/d\tau_o$ near $\tau_c = 1$ depends upon β, and is positive when $\beta > 3/2$, and negative when $\beta < 3/2$. When $dH_\zeta/d\tau_o$ is positive, S > B, and when $dH_\zeta/d\tau_o$ is negative, S < B.

Near the surface of an atmosphere where $(\epsilon + \delta)\ \tau_o < 1$, $dH_\zeta/d\tau_o$ is negative because of the escape of line photons from the atmosphere. Thus S drops progressively further below B as the opacity becomes lower.

The behavior of S/B near $\tau_c = 1$ is shown in Fig. 1 for $\epsilon = r_o = 10^{-4}$ and a Voight parameter a = 0.01. The amount by which S/B departs from unity depends upon all the parameters of the problem, but generally shows the behavior exhibited in Fig. 1.

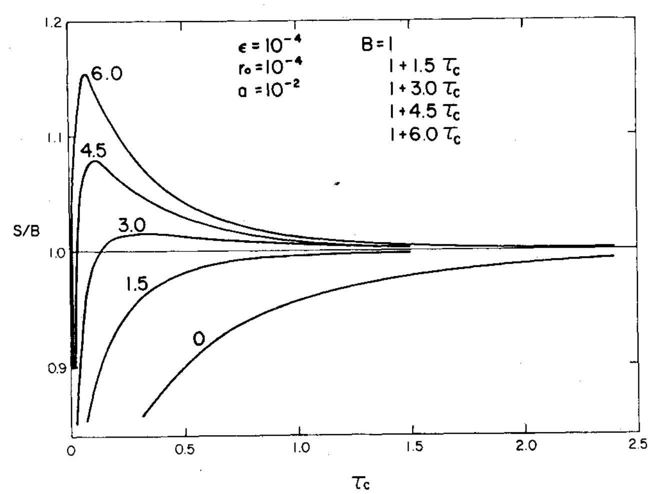


Fig. 1 Changes in the ratio S/B near $\tau_c = 1$ for different values of $\frac{1}{B}\frac{dB}{d\tau}$, the logarithmic gradient of B.

The quantity (S/B - 1) is proportional to the net interchange between photon energy and thermal energy resulting from collisional processes. When S/B > 1, collisions have a net effect of destroying photons and converting the energy to thermal energy. When S/B < 1, collisions are acting in the opposite sense to create photons from the local thermal energy. For an atmosphere like the solar atmosphere, and for non-interlocked lines, S/B > 1 through most of the atmosphere in the blue-violet regions of the spectrum, and S/B < 1 in the red regions. Thus, lines of this type, primarily resonance lines, have a net effect in collisional processes of converting photon energy back to thermal energy in the blue-violet end of the spectrum and of radiating away thermal energy in the red end of the spectrum. The total effect of the line on the thermal energy balance involves continuum absorption and emission as well as collisions. These effects are under investigation at present.

A second problem of immediate interest in connection with solutions for S from Eq. (1) involves the emission reversals in the cores of the H and K lines of Ca II and Mg II. Previous attempts to reproduce these features have led to seemingly impossible values for ϵ and r_o. Much of the difficulty has been due, in fact, to the choice of constant values for ϵ, r_o, and $\Delta\nu_D$, and of unrealistic values of $B(\tau)$. When all parameters are permitted to vary with depth in the atmosphere, and realistic values of $B(\tau)$ are used, the difficulties largely disappear.

Figures 2 and 3 show computed and observed profiles for Ca II and Mg II near the cores of the lines. The computed profiles are based on values of $B(\tau)$, $\epsilon(\tau)$, $r_o(\tau)$ approximating those predicted by the HAO model chromosphere (derived from 1952 eclipse data) and values of $\Delta\nu_D$ approximating those derived by Unno. The quantities $B(\tau)$, $\epsilon(\tau)$, and $r_o(\tau)$ have been adjusted somewhat to give the best fit to the Mg II K profile.

Although there are still significant differences between computed and observed profiles, it is clear that the general features of the observed profile are suitably reproduced by the theory.

Red Giant Stars

In collaboration with colleagues at Mount Wilson, Skumanich has conducted further tests

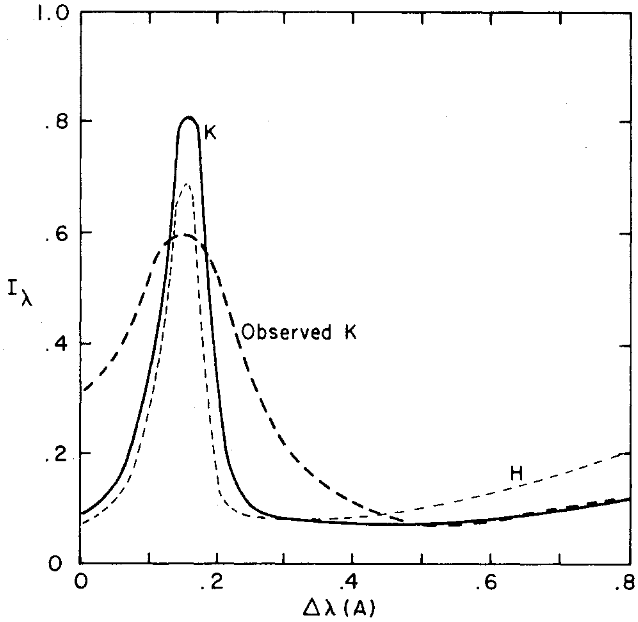


Fig. 2 Comparison of computed and observed profiles for Mg II.

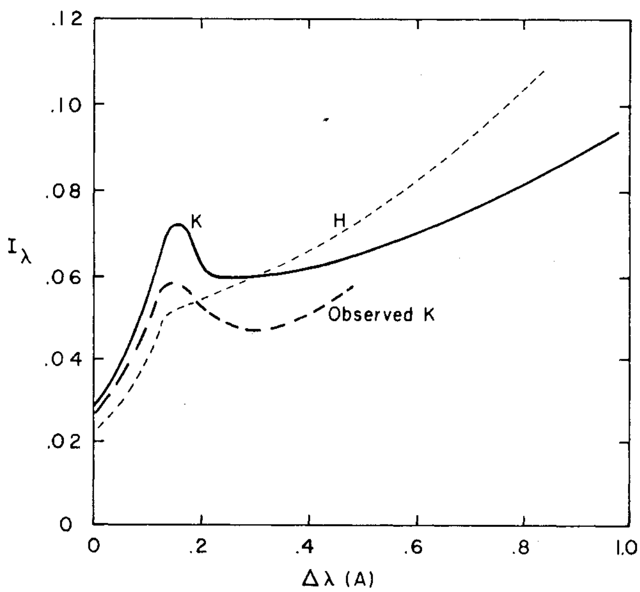


Fig. 3 Comparison of computed and observed profiles for Ca II.

of a gas-filled Fabry-Perot interferometer, for use in high wavelength resolution ($\Delta\lambda \simeq 0.03$A) scans of Ca II-chromospheric emission in red giants. Tests were made on α Taurus ($2^m.4$, blue intensity) and α Boo ($1^m.2$, blue intensity), the brightest red giants available.

From the point of view of feasibility of this technique, the tests were successful. Unfortunately, the threshold sensitivity of this interferometer does not allow it to reach any but the brightest red giants. A 4-hr run at the 100-in. Hooker telescope was necessary on α Tau to scan the 3/4A core of the Ca II line with a 5% signal-to-noise ratio. It would be impractical to obtain scans of fainter but no less interesting red giants such as β Andromeda (blue intensity $3^{m}.7$). The scans of α Tau and α Boo represent the highest resolution so far attained in Ca-K line studies. Preliminary analysis of the scans indicates previously unresolved structure of the K_2 emission peak in α Tau, and time variations in K_2 emission of α Boo with a time-scale of $\simeq 1$ hr.

Additional progress could be attained by construction of Fabry-Perot plates with still higher finesse, not an easy optical task. These would allow us to increase still further the entrance slit aperture, so that the entire stellar disk could be used. Additional gain could be obtained by a careful selection of a more sensitive photomultiplier system. Dr. Arthur Vaughn (Mt. Wilson Observatory) will continue this program in collaboration with Dr. Guido Münch of California Institute of Technology.

THE CORONA

THE WHITE-LIGHT CORONA

Many questions concerning the structure of the corona still remain unanswered. A few of the most outstanding are the following:

- What is the three-dimensional structure of coronal streamers?

- What connection exists between such streamers and more obvious surface features such as plages?

- How do magnetic fields at the surface interact with the solar wind to mold the streamers into the forms we observe?

- How does the solar wind vary from place to place in the corona?

- What is the causal connection between structures visible in the corona, the solar wind far out in interplanetary space, and geomagnetic activity?

Although it would be presumptuous to claim that our present investigations are going to solve any of these problems, they do represent long-range goals.

Coronal Observation

One of the major difficulties in the study of the corona is the lack of nearly continuous observations out to approximately six solar radii. This year, as in previous years, a large part of our effort has been directed toward developing instrumentation to secure synoptic observations of the corona. Various aspects of our efforts to improve the quality and coverage of coronal observations are reviewed below.

As was mentioned in the 1965 Annual Report, our plans to have a white-light coronagraph operating aboard the AOSO satellite were frustrated by cancellation of that satellite in December 1965. Early in 1966, our principal subcontractor on the AOSO coronagraph, Ball Brothers Research Corporation, was therefore directed to work on several engineering problems applicable to any orbital coronagraph. Their efforts to develop systems which will maintain the solar and internal alignment of the coronagraph have been particularly successful. These systems should permit the coronagraph to operate successfully in spite of misalignments of the external guiding system and thermal distortions of the optical bench of the instrument.

To replace the capabilities for large solar telescopes in orbit lost by the cancellation of AOSO, NASA has planned to mount a large, accurately guided platform on one of the manned Apollo satellites in earth orbit mission. One of the experiments scheduled to fly on this mission is a coronagraph rather similar to that developed for AOSO but benefitting from the fact that physical records can be recovered. The ATM coronagraph, as it is called, will employ photographic rather than photoelectric recording of coronal images, and will be under immediate control of the astronauts. The fact that pictures of the corona can be produced every second or so will allow investigation of rapidly developing transients in the corona, which would have been inaccessible to the photoelectric scans made by the AOSO coronagraph. Moreover, the astronaut will be able to select particular periods, such as one immediately following a flare, for more intense observations. The projected duration of the mission -- up to 56 days -- will still allow considerable study of the synoptic development of structures in the outer corona.

This instrument is being designed and developed by Ball Brothers Research Corporation; the Apollo telescope mount (ATM), which will guide all of the experiments on the sun, is being developed at Marshall Space Flight Center in Huntsville, Alabama. The present schedule calls for launch of this system in approximately two years -- about the time of the next solar maximum. Hopefully, a prototype of this instrument can be tested in the guiding gimbals used for the Coronascope II apparatus. As in past years Eddy, Newkirk, and Ross have been concerned with this work.

The flights of the Coronascope II system revealed a difficulty in predicting the actual performance of the instrument by laboratory tests. Unfortunately, it is impossible to make a completely realistic laboratory simulation of conditions at either balloon or satellite altitudes. The "synthetic sun" can never be placed an infinite distance away, and scattering in the air path in the laboratory precludes making sensitive analyses of the scattered light level actually produced in the instrument. However, several experiments performed by Ross have shown how the finite distance of the synthetic sun can be allowed for in evaluating an instrument. Also, an evacuated test tunnel 100-ft long, which will allow instruments to be tested definitively, has been designed and will be completed this spring. Experiments with the Coronascope II system in this tunnel will allow a detailed comparison between in-flight and laboratory performance of this instrument, giving us an estimate of the validity of the test procedures.

A unique problem in operating a coronagraph in a manned satellite is that the optical environment may be contaminated by a life-support system. Newkirk has examined the dynamics of particulate material ejected from manned spacecraft. He found that debris thrown from the vehicle will accompany it in orbit as a surrounding cloud for nearly an hour. Moreover, if most of the water vapor present in the spacecraft cabin condenses to form ice crystals as it escapes, the radiance of the sunlit cloud of debris may be so high as to preclude observations of the solar corona and other faint astronomical objects. This debris cloud may explain the difficulty which astronauts have experienced in seeing stars in the daytime. The seriousness of this problem has stimulated several groups at NASA to investigate it by means of actual measurements during space flights, as well as by the evaluation of some of the crucial parameters in the laboratory.

Occasionally an unusual opportunity for study of the corona presents itself unexpectedly. Such was the case in June 1966, with the successful landing of the Surveyor I spacecraft on the moon. With the urging of Eddy, Harvey, and Newkirk, the Jet Propulsion Laboratory performed a search for the solar corona just after sunset on the moon on 14 June 1966. The search was successful and the corona was visible on the photographs out to a distance of approximately four solar radii. There is excellent correlation between the inner corona as seen by Surveyor I and by the koronameter operated by Hansen on Mauna Loa. The experiment demonstrated the feasibility of observing the solar corona from a moon-based observatory. The fact that the corona was visible shows that a lunar ballistic atmosphere, if it is present at all, is extremely tenuous. Quantitative analysis of Surveyor I data will allow us to establish upper limits for any residual lunar atmosphere. Future Surveyors should be able to examine those portions of the corona and zodiacal light which are inaccessible from the surface of the earth.

Although progress in making observations of the intermediate and outer corona from space is encouraging, the quality of such observations is likely to remain inferior to those which can be obtained at a natural eclipse. During the spring and summer of this year a coronal camera was developed which could produce high-resolution, photometrically useful pictures of the corona out to approximately six solar radii. Many unique features were incorporated in its design in order to facilitate transport and assembly at a remote eclipse site. Of course, in order to make optimum use of the precious seconds of totality, the instrument was controlled completely automatically. One of the major difficulties in photographing the corona is the steep radial gradient of intensity. Ordinary photographs are properly exposed only in a rather narrow annulus in the corona. To circumvent this limitation the Observatory coronal camera contained, in one of its filter stations, a special filter with a radial gradient of transmission calculated to compensate for the drop in intensity of the corona with increasing distance. The photographs made through this filter were successful beyond expectation, and show extraordinary detail in the corona from the chromosphere out to the limit of the field at 5.5 solar radii. Additional photographs of the corona through polaroids will allow us to determine the distribution of material in the corona at that time. When coupled with magnetic observations, these data can, we hope, be combined to form a more coherent picture of the interaction of the corona with solar magnetic fields.

Coronal Analysis

Several analyses of the results of past eclipse expeditions and balloon flights have been performed during the year. Newkirk examined in detail the photographs made during the 1963 expeditions for transient features in the corona. Under visual inspection, these photographs, taken during a period of approximately 100 minutes, show many apparently changing features. Unfortunately, detailed photometric analysis shows that the majority of these changes are due to subtle differences in observing conditions and image contrast at the various stations. The only motions which could be definitely established were rather leisurely translations in the boundary of coronal streamers, such as were observed many years ago by Bugoslavskaya.

Under the guidance of Newkirk, Bohlin has made an intensive study of coronal data obtained about the time of the 30 May 1965 eclipse. These data include eclipse observations, photographs made during two Coronascope II flights, and tracings made by the koronameter on Mauna Loa. This study has resulted in a three-dimensional model of a coronal streamer out to ten solar radii, and establishment of the fact that some streamers do, in fact, lie over prominences. Other streamers, however, appear to be rooted in completely nondescript regions. One of the streamers observed was visible during several months and, because of its high latitude, could be observed over the pole as it passed behind and in front of the sun. The observed "garden hose curvature" in this streamer allowed several important parameters of the solar wind to be estimated. First, the profile of the velocity of the solar wind was determined in the inner corona. Second, rigid rotation of the corona was found not to extend beyond approximately three solar radii. This latter parameter is of interest both in the context of the solar wind and in connection with the evolution of the sun. If, as some investigators believe, the corona were to rotate rigidly out to 20 or 30 solar radii, the sun could have lost sufficient angular momentum during its lifetime to be of significance in its evolution. Our observations suggest that the solar wind can be ignored in this aspect of the evolution of the sun. The velocity structure of the solar wind which we derive agrees reasonably well with the theoretical models; however, it is not sufficiently accurate to allow the selection of one model as preferable to another.

Harvey and Newkirk have carried out an investigation of polar plumes visible on several of the HAO eclipse observations. Fourier analysis of intensity distribution across the pole was used as the most objective way to determine the average size and the density structure of these features. It is of interest to note that the mean diameter of plumes -- 30,000 km -- is the same as that of the chromospheric supergranulation which forms a coarse magnetic network over most of the sun away from active regions. To test whether the magnetic field associated with supergranulation could, indeed, form tubes, which when filled with coronal material would become polar plumes, the magnetic field above a simulated network was calculated. It was found that when the network was of predominantly the same magnetic sign, the field configuration represented the plumes rather nicely. In a mixed network, on the other hand, all evidence of plumes was obliterated. This information, plus the positive association found between polar plumes and abnormally bright chromospheric faculae at the pole, support the general conclusion that plumes originate at these bright faculae, where the flow of material into the corona is abnormally high. The magnetic field constrains the material to remain in an isolated tube, which then takes on the form of the lines of force around the general magnetic field of the sun. Away from the poles the fixed nature of the magnetic field prevents any such aligned structures from forming. There is also evidence that the solar wind drags these filaments out into the interplanetary medium to form the fluctuations in intensity which are observed by spacecraft and radio star occultations of the corona.

Interplanetary Medium

The interaction of solid particles in the solar system with the sun is especially fascinating. Kaiser, under Newkirk's guidance, has been investigating the thermodynamics of small particles in the solar system, giving particular attention to the manner in which they evaporate close to the sun. Although the fact that solar radiation will carve a vacancy in the zodiacal light cloud immediately around the sun is well known, Kaiser's detailed calculations show that many particles can penetrate further into the corona than was previously suspected. His models allow calculation of the thermoradiation which should be expected from the interplanetary medium as the particles evaporate. Comparison of these calculations with the observations made by the Johns Hopkins group at the last eclipse will be of particular interest.

Koronameter

The purpose of our operation of the koronameter continues to be the study of the K-component of the solar corona using ground-based astronomical techniques. With the koronameter, observations are being made of the inner corona on a continuing basis, typically to a height of one-half solar radius above the limb. From these measurements we hope to enlarge our understanding of the electron corona itself -- its form, spatial distribution, and development, and its association with photospheric and chromospheric features. These observations are also proving to be a valuable adjoint to the balloon and natural eclipse photographs of May 1965 in constructing detailed models of the coronal streamers, as described in the preceding section.

In collaboration with Dr. Harold Loomis of ESSA, Shirley and Richard Hansen have carried out extensive statistical studies of the past three years' koronameter data. By autocorrelation analysis of successive days' observations, they have been able to confirm that the electron corona displays a differential rotation, having a somewhat longer synodic period at higher latitudes than near the equator. Similar results have been reported before, particularly by a French astronomer, Trellis. However, 1964 and 1965 koronameter observations at 1.125 solar radii reveal a striking difference in rotation rates between the more active northern hemisphere and the southern hemisphere, which was practically devoid of any sunspot or plage features during those two years. At 50° latitude, the average rotation period is 28 days for the southern hemisphere and nearly 30 days for the northern hemisphere. These studies are now being extended to greater distances from the solar limb.

In addition to studying the reappearances of bright regions on the limb, fluctuations of the observed signal were examined. Results are illustrated in Fig. 4. Plotted against solar

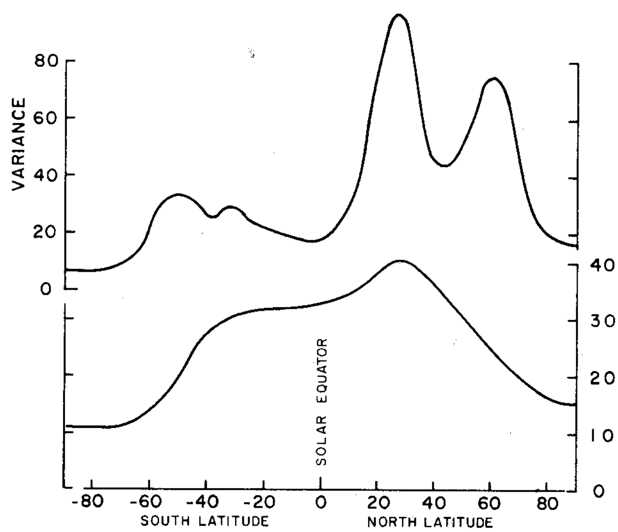


Fig. 4 Means and variances of the brightness of the corona at 1.125 solar radii (measured from the center of the disk) as observed with the koronameter during 1965.

latitude are the means and variances of some 250 days of koronameter observations at 1.125 solar radii during 1965. Several characteristics are readily apparent:

- The maximum corona appeared at 30^{o} north latitude, approximately the same location as the spots and plages. There was essentially no chromospheric activity in the southern hemisphere during the year, so the distribution here closely represents the "quiet" electron corona.

- The average corona in the north polar region appeared to be nearly 50% brighter than in the south polar region. This may have been due entirely to projection of high latitude enhancements above the apparent north pole. The density of the corona above the poles remains an interesting, unanswered question.

- The variances show two well defined belts of activity at 30^{o} and 60^{o} latitude in the north and also, to a much lesser degree, in the south. The 30^{o} latitude coronal enhancements are presumably associated with spots and plages, while 60^{o} latitude activity is probably associated with the polar crown of filaments, thus suggesting two distinctly different types of K-coronal formations.

The koronameter has been in use at its new location, at the Mauna Loa Observatory on the island of Hawaii, for just one year. The move from Haleakala was profitable. There we worked on a side of the University of Hawaii's equatorial spar in the Mees Laboratory, and ours was but one of a number of diverse experiments being carried out in the same facility. At Mauna Loa, with our own telescope enclosure, we are better able to maintain the "clean-room" type of environment for the koronameter which is essential for sensitive measurements. Also we seem to have escaped from the swarms of Nysius insects which seriously degraded our observations at Haleakala many days each year. Last summer we carried out standardized insect collections at the three summits, Haleakala, Mauna Kea, and Mauna Loa, and also at control points at 13,000 ft on Mauna Kea and Mauna Loa. These collections tended to confirm our expectations that the great concentrations occur just within a few hundred feet of the summits. Insect samples are being identified and analyzed by entomologists of the Bishop Museum, Hawaii.

Solar Wind

As a part of his doctoral research, Kopp has developed a general theory of shock propagation in nonuniform media. His theory has been used to calculate the structure of a spherical stellar atmosphere which is maintained in a quasi-steady dynamical state by a balance between the energy exchange processes of radiation, thermal conduction, wave dissipation, and atmospheric expansion. Atmospheric models have been constructed by means of a computer program; in the case of the sun, they provide a unified picture of energy balance in the entire outer solar atmosphere, extending from the base of the chromosphere-corona transition layer to the earth's orbit and beyond. A single model appears capable of simultaneously representing large-scale observations of coronal electron densities, chromospheric Lyman-α emission, coronal EUV-line emission of heavy elements, and the solar wind in interplanetary space.

EMISSION LINE CORONA

Because of its two lines in the infrared, arising from different levels, Fe XIII is a particularly attractive probe of coronal density and temperature. Malville has calculated the intensity ratios of $\lambda 10747$ and $\lambda 10798$ in an 18-level model ion having $3s^2 3p^2$, $3s3p^3$, and $3s^2 3p3d$ configurations. The collision strength for the $3s^2 3p^2$, $^3P_0$-$^3P_1$ appears to be close to 0.03 on the basis of comparison with the observed intensity ratios. Studying the bright condensation of 4 February 1962, using Climax observations of the infrared lines made with the image tube, Malville found an abundance of iron relative to hydrogen of approximately 6×10^{-5}.

Eddy and Malville have completed analysis of $\lambda 10747$ and $\lambda 3388$ measurements, obtained on

Bellingshausen Island with their two-channel photometer during the eclipse of 30 May 1965. Their results are summarized in Table 1, which gives the observed polarizations in the continuum, the polarizations of λ10747, and the line-to-continuum ratios in λ 10747. In the UV channel only the continuum was measurable, so only an upper limit on the λ 3388 line to continuum ratio can be given. To our knowledge, these are the first observations of the linear polarization of λ10747.

Table 1

Height ($r/R_\odot$)	P(%) Cont.	P(%) Line	I_L/I_c
1.2	32	8	15
1.39	31	11	18
1.55	43	30	14.8
1.72	37	23	10.7

Table 2 lists estimates of the lower limit of the iron-to-hydrogen ratio in the corona and of the abundance ratio found, using an assumed distribution of iron among the various states of ionization.

Table 2

Height ($r/R_\odot$)	$\frac{N(Fe)}{N(H)}$, Lower Limit	$\frac{N(Fe)}{N(H)}$
1.2	1.0×10^{-5}	6.1×10^{-5}
1.39	1.4×10^{-5}	9.8×10^{-5}
1.55	1.6×10^{-5}	9.4×10^{-5}
1.72	1.4×10^{-5}	8×10^{-5}

Both estimates of the iron-to-hydrogen ratio in the corona are consistent with other determinations, being some 20 times greater than that for the photosphere. Our eclipse determination has the advantage of relying upon measurements made far from the limb in a region of the corona where the infrared lines are largely excited by the photospheric radiation field. Because of this, interpretation of line intensities does not depend strongly upon unknown density fluctuations along the line of sight, or upon uncertain collison strengths.

Malville, aided by William Hatt and Edward Schmahl, graduate students at the University of Colorado, and Hultquist, succeeded in observing λ 10747 and λ 5303 out to 1.75 solar radii during the eclipse of 12 November 1966 from the altiplano of southern Bolivia. The experiment was similar to that on Bellingshausen Island: interference filters were rotated to provide wavelength scans at the two wavelengths. Cooled S-1 and S-20 photomultipliers were used, and the signals were recorded with logarithmic response on strip chart recorders. A modification of the infrared equipment included a stepped half-wave plate to measure the polarization of the line. The sky was clear, the equipment worked, and the results are being analyzed at the end of the report year.

1966 Eclipse Airborne Observations

The discovery of polarization in the λ10747 emission line of Fe XIII at the 1965 eclipse encouraged us to study the effect in more detail at the eclipse of 1966. The variation of polarization with distance above the solar limb, detected in the single radial scan in 1965, suggested that a more accurate measurement of the direction and strength of polarization throughout the corona might lead to information on the coronal magnetic field -- a hitherto unmeasured parameter of the corona. The resonance scattering process responsible for emission line polarization predicts a purely radial orientation of the electric vector of radiation; the presence of a significant magnetic field would alter this direction. Moreover, measurement of emission line polarization throughout the corona can be used to determine the run of iron abundance through the corona, and to separate regions of radiative and collisional excitation. This separation is possible since polarization will be present only under conditions of dominant radiative excitation.

An experiment to study the two-dimensional form of $\lambda 10747$ emission and polarization was carried out by Eddy and Firor at the eclipse of 12 November 1966. The Observatory was granted a window for this purpose on the Convair 990 jet aircraft of the NASA Ames Research Center, operated for this expedition from Porto Alegre, Brazil. An 8-in. infrared telescope was gyroscopically guided on the corona through a 10 x 14 in. window of optical quality. A coronal image was formed through a $\lambda 10747$ interference filter of 14A half-width on the face of a two-stage image tube, furnished by the Department of Terrestrial Magnetism of the Carnegie Institution. The color-converted image was recorded on blue sensitive film at the image tube phosphor. The result is a series of unusual coronal photographs, taken in the light of the $\lambda 10747$ emission in three states of polarization. A similar series was taken for comparison in the nearby continuum at 1.06μ through a second filter. The pictures are of high quality, with resolution limited by the image tube to about 15 arc seconds; they show the intricate form of the emission corona extending as far as 1.5 solar radii in some regions. A high and extensive structure of coronal loops is visible in the emission line photographs at the west limb, and the general enhancement of coronal emission is obvious at the base of the three dominant coronal streamers seen in the K-corona at the same time. Eddy and Firor will work on detailed analysis of the photographs in 1967 to see if polarization can be detected and to measure emission line intensity throughout the corona.

Equally encouraging in this experiment was the performance of the gyroscopic stabilization unit, developed and built in the Observatory electronic and mechanical facility by Lee and Lacey. Beginning with a concept developed by Richard Dunn at Sacramento Peak for his 1965 eclipse coronal spectrograph, Lee and Lacey built a completely new system around the infrared telescope. In the improved design the center of system mass was located near the floor of the aircraft; a more sophisticated servo and torque motor system was used also. A low-frequency booster system to correct the dominant mode of aircraft motion, and an auxiliary roll-rate gyro, gave demonstrable improvement in guiding. Two-axis pointing accuracy achieved was about 2 arc seconds, rms, on the best flights. This engineering achievement demonstrates to us the promising future of the airborne platform in making eclipse and other observations.

SOLAR ACTIVITY

SUNSPOTS

One of the basic mysteries confronting solar physicists is the morphogenesis of sunspots. In spite of considerable advances in solar physics throughout the past fifty years, relatively little has been achieved toward a satisfactory theoretical understanding of the sunspot phenomenon. Two decades ago, it became clear that the then newly formulated equations of magnetohydrodynamics would form the nucleus of any comprehensive theory of solar magnetic regions. The primary difficulty in the application of these equations, however, is their extremely nonlinear nature.

A second difficulty, until recently, was the extremely large value calculated for the electrical conductivity of the photosphere. The value of conductivity estimated by Cowling in 1952, on the basis of a fully ionized plasma, implied sunspot decay times of about 300 years instead of the observed value of about ten days. Investigations of partially ionized plasma, whose nature more accurately represents the umbral conditions, revealed that electrical conductivity, and consequently theoretical decay time, should be decreased by a few factors of ten. This decrease in decay time was still not sufficient to bring theory and observation into even approximate correspondence. Two years ago in Germany, E. H. Schroeter showed that as a result of better observations of umbras, which consistently yield lower temperatures, sunspot conductivity should be recalculated using a much smaller degree of ionization. The new calculation indicated that electrical conductivity of sunspots should be revised downward by another few factors of ten. Finally, the use of experimental cross sections also gave a decrease by a factor of ten. Hence the sunspot umbra was finally estimated by Schroeter to have an electrical conductivity nearly 10^4 times less than that used by Cowling, which would indicate a probable sunspot decay time of about ten days.

Although the Schroeter conductivity value provides reasonable decay times, there is still some uncertainty as to which scale length to choose in numerical estimates. In an attempt to achieve a more accurate understanding of the decay of a sunspot, Altschuler carried through a numerical computation of the diffusion of a magnetic field in a medium of variable electrical conductivity, using values applicable to the solar atmosphere in the vicinity of sunspots. Because of the nonlinearity of the equations, the calculation was simplified by the assumption of stationary plasma. Since within the umbra the magnetic Reynolds number is now within an order of magnitude of unity, this assumption is not as drastic as was previously the case.

Altschuler's calculation indicated that as a result of the low values and large gradients of electrical conductivity in the vicinity of sunspot umbras, any electric current in the umbra will drift, in periods of a few hours, to more highly conductive regions. If one starts with a ring current in the photosphere (and assumes the minimum of electrical conductivity to correspond roughly with the photospheric temperature minimum), the ring current will migrate to regions above and below the sunspot. The implication is that the photosphere, particularly the umbral region, is current-free most of the time. Bright rings, which are often observed to encircle sunspots, are located in the chromosphere and deep within the photosphere, in regions consistent with those computed for the ring current. Altschuler believes that these observed bright rings may be explained at least partially by ring currents that have migrated along gradients of electrical conductivity.

Nevertheless, the primary difficulty of sunspot theory -- the nonlinearity of the MHD equations -- still remains. Until this problem is attacked there can be no clear understanding of the interactions of the magnetic and velocity fields. Moreover, without a solution of the nonlinear equations one cannot isolate the primary cause of the sunspot phenomenon because one cannot ascertain how much information pertinent to observed sunspot morphologies is already contained in the existing formulation.

In an attempt to reach the core of the sunspot problem, Altschuler, Nakagawa, and Lilliequist are resorting to a brute-force, numerical solution of the nonlinear equations. The problem involves the simultaneous solution of two nonlinear partial differential equations slightly modified from the original formulation of Chandrasekhar. A computer program is now being "debugged." It is hoped that through these endeavors a better understanding of sunspot dynamics will evolve.

PROMINENCES AND FLARES

Malville has initiated two studies of the physics of prominences: (1) magnetograph observations of prominences and the relationship between prominence fields and their spectral characteristics; and (2) spectrographic observations which can define quantitatively the temperature structure of prominences.

Malville and Porter have continued the magnetograph observations of limb prominences started by Rust and Porter. During the summer and fall of 1966, more than 30 magnetograms were taken. Except for one limb surge, all the prominences showed fields of less than 20 gauss. The surge of 19 September, which apparently initiated a Type II burst observed on that day, had a magnetic field of approximately 110 gauss.

In contrast to the large field observed in a fast surge, evidence is found in quiescent prominences for an inverse relation between the speed of small knots of material and the strength of the magnetic field. Even in long-lived, quiescent prominences there are small Ca II emission knots, separate from the main stationary body of gas, that occasionally show speeds exceeding 100 km/sec. In 15 quiescent prominences studied by Rust in the fall of 1965, velocities of Ca II emission knots vary from 1 to 90 km/sec, and average fields vary from 2 to 14 gauss. For fields from 2 to 7 gauss, the average maximum velocity is 50 km/sec, whereas for fields from 7 to 14 gauss, the average maximum velocity is 30 km/sec.

Malville also obtained spectra in the UV with the Climax 16-in. coronagraph-spectrograph for the purpose of studying the Balmer continuous emission and metallic emission lines close to the atmospheric cut-off. The spectral region below 3400A is particularly rich in Ti II lines, and these have been photographed to Ti II $\lambda 3217$.

Malville and Charles Smyth, a graduate student at the University of Colorado, have made a detailed analysis of intensity ratios of H, He, and Sr II lines in a large hedgerow prominence of 6 November 1965, using a grid of some 25 positions in the prominence. There is evidence for systematic changes in temperature throughout the prominence as the intensity ratio Sr II $\lambda 4078$/He $\lambda 4026$ varies from 0.5 to 2.2, and H $\lambda 3388$/He $\lambda 3388$ varies from 0.4 to 2.8, in such a fashion that the product of the above intensity ratios tends to remain constant with height.

Helium Lines in Flares and Prominences

Tandberg-Hanssen attempted to determine the excitation conditions in prominences of different degrees of activity. His aim was to understand the relative importance of collisional versus radiative excitation in such objects, and to determine the densities in prominences -- a parameter that is poorly known. To achieve this he used information on several helium lines observed in limb prominences. Most of the observational data were obtained in the previous report period and reported on then. The next step -- solution of the coupled statistical equilibrium equations and the equations of transfer in the lines -- was studied in the present period.

The triplet structure of He I and the populations of its d and s levels were first tracked independently of the singlet structure. This step was justified by the fact that some observed deviations from the LTE values of the d-to-s population ratios in dense objects probably are due to collisional excitation, and are independent of the radiation fields in the singlet structure. After this step, the solution of statistical equilibrium equations to account for observed ratios between singlet and triplet lines was attacked. It was soon found that successful completion of both these steps depends on availability of reliable collisional cross sections for excitations of levels with principal quantum number up to $n = 5$. Dr. Michael Rudge (Queen's University of Belfast) provided information on several of the transitions involved, but at the end of the year some cross sections are still unknown. The program has, therefore, been slowed down until the remaining crucial data become available.

Comments on a Flare on 20 September 1966

A flare on 20 September 1966 provided an excellent opportunity to study several aspects of the complex flare phenomenon. Tandberg-Hanssen used filtergrams, spectra, and magnetic observations secured during the flare in an attempt to understand the behavior of the flare and its interaction with the nearby sunspot. The flare began simultaneously as a bright knot in the sunspot umbra and as a brightening of a nearby plage area. It later developed into the characteristic "two parallel ribbon" type often associated with the disappearance of a prominence. The history of this flare suggests that in some complex flares different generating mechanisms may be at work simultaneously.

Of considerable interest are the spectra of the Ca II, K, and H lines. The lines are fairly broad in those parts of the flare that occur in the plage areas, but the strongest flare knot, which occurred over the sunspot umbra, has narrow Ca II lines. It is tempting to ascribe this narrowing of the flare-line profiles to an inhibition of motions of the Ca II ions caused by the magnetic field in the sunspot. If this interpretation is correct, one should expect a similar narrowing of the line profiles from the sunspot proper when and if the sunspot shows emission lines of Ca II. Also, since the magnetic field configuration probably varies considerably from one sunspot to another, one should not expect to observe a unique K or H line profile in a sunspot with Ca II emission. This conclusion is consistent with observations.

The magnetic data obtained from the flaring knot over the sunspot are subject to some uncertainty because of increasing cloud cover during the observing period. Nevertheless, two conclusions may be drawn: (1) the magnetic field as measured in H-α over the sunspot had decreased to a value of about 100 gauss at the level where the flare knot appeared in Ca II light; (2) the magnetic field in this part of the flare seems to have undergone fairly rapid fluctuations, but on the whole there is no significant change in the field strength over a period of 20 minutes during the maximum phase of the flare. The fluctuations do not seem to constitute a regular oscillation, even though a roughly 4-min period cannot be ruled out.

Magnetograph Observations

Tandberg-Hanssen spent considerable time on the problem of the role of magnetic fields in different aspects of solar activity, his thesis being that solar activity is the manifestation of interactions between magnetic fields and the solar plasma. Magnetic fields in and around quiescent prominences were studied by Rust, whose work culminated in a Ph. D. thesis. At the time of this writing considerable effort is being spent on establishing the correlation between the extent of the optical plage found around quiescent prominences and the strength of the corresponding magnetic plage whose magnetic field supports the prominence. The development of the magnetic field in young plages is being studied by Schoolman, who intends to use the data for a Ph. D. thesis.

RADIO BURSTS

Although Type III bursts are basically coronal phenomena, at their high frequency starting points they extend into the chromosphere-corona interface. Two effects limit the intensity of these bursts as they first make their appearance: collisional damping of plasma waves, and free-free absorption. Free-free absorption provides the source of attenuation which increases most rapidly with increasing frequency, and which probably determines the frequency at which bursts are first visible. Malville has found a systematic variation of the starting frequency of Type III bursts from the Ft. Davis sweep-frequency data. The starting frequency decreased from an average of 380 MHz in 1960 to an average of 190 MHz in 1965. If we assume that free-free absorption is responsible for this variation, this finding places a restriction upon a model of the corona-chromosphere interface: near maximum the steep temperature gradient must set in near $N_e = 1.9 \times 10^9$, whereas near minimum it occurs near $N_e = 4 \times 10^8\ cm^{-3}$. Using the chromospheric density model that Grant Athay obtained from the 1952 eclipse, and assuming a constant electron pressure through the interface, 10 db absorption should occur at the observed starting frequency for a chromospheric electron pressure of 0.18 dynes/cm^2 at maximum and 0.03 dynes/cm^2 at minimum. The temperatures at "break-out" plasma levels in this model are 740,000^{o}K at maximum and 500,000^{o}K at minimum, with a 2,000,000^{o}K corona. On each day there may be considerable variation in starting frequencies of individual bursts; such variation provides an interesting insight into the question of temperature and density inhomogenieties in the interface. Other metric bursts should be similarly affected by free-free absorption; in fact the same effect appears to occur for noise storm bursts, judging from an earlier finding that noise storm bursts consistently occur near the average starting frequency of Type III bursts.

Malville investigated the variation of other characteristics of Type III bursts with solar activity, using the Boulder decametric observations. Using periods of low activity he has been able to obtain a more satisfactory measure of the association between Type III bursts and flares: it appears that less than 20% of the bursts are produced by detected flares.

During 1966, Malville and George Dulk, of the University of Colorado, obtained high-speed records of Type III bursts at 36, 18 and 9 MHz. These records are being analyzed to determine rise times and decay times and, eventually, coronal temperature gradients.

Malville completed his analysis of spike bursts following the proton flare of 5 February 1965, using data he collected at Michigan. Spike bursts have decay times of 0.05 sec, shorter by a factor of two or three than those of Type I storm bursts. However, with regard to bandwidth, polarization, and association with active regions, there appears to be no fundamental difference between spike bursts and Type I storm bursts. The mechanisms which have been proposed for both utilize particle streams in some manner, either to excite plasma waves or to provide a non-thermal anisotropic electron velocity distribution in which negative absorption of gyro-radiation occurs. The shorter duration of spike bursts may be due to the shorter lifetime of either particle streams or resulting plasma waves. If decay times are controlled by the break-up of particle streams, the observed decay times yield estimates of 1.6×10^9 cm/sec for the velocities of the streams responsible for the non-equilibrium distributions in the corona. On the other hand, if collisional damping determines the decay rate of the bursts, particle velocities must be higher. At velocities close to the electron thermal velocity, Landau damping proceeds very rapidly. Only at velocities above approximately 4×10^9 cm/sec is the Landau damping time longer than the observed decay time of 0.05 sec. However, the velocity cannot be so high that the particle stream will penetrate a large distance into the corona and produce a broad band burst. The velocity above which particle streams will cover distances corresponding to the observed frequency spread is approximately 6×10^9 cm/sec. At present we can limit the velocities of particle streams responsible for spike bursts to the range 1.6 to 6×10^9 cm/sec.

FLARE PREDICTION

Work on evaluation of the effectiveness of flare predictions was renewed during the year. Gray joined the staff in September and, in cooperation with ESSA, began a study of daily forecasts issued by the Solar Disturbance Forecast Center during 1966. A program of verification for these forecasts has been completed and is being routinely run by ESSA on their forecasts.

Evaluation of the usefulness of forecasts of any natural parameter is quite different from measuring the usefulness to a research program of knowledge of the value of the same parameter, and so forecast evaluation presents some difficulty to those accustomed to dealing with research results. In general, a forecast number has no research usefulness, except that a highly successful forecast usually implies a high degree of understanding of the phenomena involved. Therefore the usefulness of forecasts must be evaluated with regard to the customer, the person who will finally use the forecast to make decisions. Gray has postulated several different idealized customers with problems which require utilization of flare forecasts. He assumes that the user will respond in an optimum way, from a decision theory point of view, to the existence of the forecast, and will utilize the forecast in a consistent manner. It is possible to evaluate the utility of the forecast to this idealized customer and to determine whether the decisions the customer makes are, in fact, improved by the utilization of the forecasts. This approach not only relates the work on forecast evaluation to real problems facing various agencies in the United States today, but also clarifies the trade-offs that must be made if one insists on extreme certainty in prediction.

The utility of an imperfect forecast depends largely on the customer. Consider, for example, a forecast of the probability of occurrence of a proton event near the earth resulting from a solar flare. If a customer needed accurate predictions of days on which no proton event would occur, a set of forecasts predicting a very low probability of occurrence of a proton event, which were indeed fulfilled, could be of high utility to the customer even though they never correctly forecast the occurrence of a proton event. Another customer, who needed to know beforehand when a proton event would occur, but who was uninterested in zero days, would find these same forecasts worthless.

An equally important part of the verification practice is to measure the characteristics of the forecasts themselves -- in other words to ascertain what percentage of each type of forecast is fulfilled, and within what accuracy limits. This procedure has frequently been considered the entire problem of forecast verification, but it can be seen from the discussion above that the customer point of view is also essential in verification.

Gray has developed a procedure for measuring the utility of a set of forecasts stated in probability terms, using the statistical decision approach described above, and has tested the usefulness of this procedure on the ESSA-SDFC forecasts. A method of computing confidence limits for a simple application of this procedure has been completed; work is continuing to develop a confidence limit for the more general case.

THE SOLAR SYSTEM

JUPITER AURORA

Dulk and Eddy continued an observational search (begun in 1965) for visual auroras on Jupiter. The character of the decametric radio emission from that planet has suggested that a visible recombination emission spectrum might be observed in the magnetic auroral zones on Jupiter at the times of observed decametric radio bursts. Such a phenomenon would result, presumably, from impingement of energetic electrons in local regions of the planet's atmosphere. The local quality of the predicted auroras, their intermittence, and their predicted weakness make the observation difficult.

Dulk and Eddy carried the search to a new lower limit of sensitivity in a spectroscopic search of high spectral and spatial resolution, using the fine Coude spectrograph at the 84-in. telescope at Kitt Peak National Observatory. They obtained spectra of Jupiter with resolution of about 0.2A, an improvement of more than 1000 over the best previous result. Dulk's predictions of the time and loci of expected events, based on his study of the controlling effect of the satellite Io on the decametric emission, permitted them to localize areas of expected emission to small regions of about 1/100 the diameter of the planet, and to secure spectra there. Observations were obtained during eight nights in November and December 1965, and February and March 1966, at times which coincided with predicted radio emission. Eighteen usable high-resolution plates were obtained, five in the blue with dispersion 2.2 A/mm.

No emission is obvious on any of the plates. Had aurorae of brightness 3 kR or more been present, they should have been detected as resolved emission bumps in the profiles of the stronger hydrogen and helium lines in the reflectance spectra of the planet. Second-order analysis of the plates will be carried out in 1967, in which the detailed profiles of the H, He, and H_2 lines will be examined for asymmetries which could result from unresolved emission features. Dulk and Eddy also plan to study the NH_3 and CH_4 planetary absorption lines on the spectra to determine whether Spinrad's anomalous line tilt was present on any of the plates.

LABORATORY STUDIES

VACUUM UV AND X-RAY SPECTROSCOPY

The theta-pinch machine described in the last report has been operated throughout the year. As with any device operating at the edge of a rapidly advancing technology, the system has been, and will continue to be, subject to many developmental changes. During the year, House and Wolfe made a major change in the capacitor bank, converting from ignitron switches to three-element triggered spark gaps. This improved the reliability of operation greatly; pre-fires were virtually eliminated, and accumulated delay time for firing 16 capacitors simultaneously was reduced to less than 100 nsec.

The temperature monitor built by Blake, described previously, is now in use. This two-channel photoelectric instrument measures the relative x-ray flux transmitted through thin beryllium or aluminum foils. From the measurements, which give the slope of the x-ray bremsstrahlung spectrum, thermal electron temperatures from 200 to 350 ev have been obtained.

Using the machine in its present configuration, Deutschman completed the data for his thesis. He measured approximately 100 previously unidentified lines in the highly ionized spectra of S, C1, A, K, and Ca. The observed transitions $2s^22p^n$ - $2s2p^{n+1}$ (n = 1-5) are in the B I to F I isoelectronic sequences, which end on the ions Ca XII - XVI, of obvious interest in the solar corona. The highest ionization observed in this sequence was Ar XIII, which requires 620 ev to produce.

The dual-purpose crystal-grating x-ray spectrometer, constructed under Blake's direction, is essentially completed. For testing and alignment purposes, measurements of the Lyman-line of O VIII (740 ev) have been made, using the theta-pinch machine as a light source. Although a strong O VIII signal has been observed, difficulties were encountered in the measurement of line profiles, which were not encountered where time-integrated spectra were recorded with the grazing incidence spectrograph. Hard x-rays of several kilovolts interfered with and masked the soft x-rays associated with the emission lines, and the plasma conditions varied between shots. Attempts will be made to correct these conditions.

Plasma Kinetic Theory Calculations

Numerical solutions of the Fokker-Planck equations of plasma kinetic theory have been carried out by House to investigate (1) possible departures from Maxwellian equilibrium under solar coronal conditions, and (2) influences of known departures from Maxwellian equilibrium in laboratory plasmas. For solar corona calculations, an inelastic collision term was added to the Fokker-Planck equations to represent the process of collisional excitation, followed by radiative decay, which selectively transfers electrons from the high-velocity tail to low velocities. A gaussian distribution of ion velocities, crudely representing a shock front, was used as the source of energy to counterbalance radiation loss. The energy transfer from ions to electrons is accounted for in the Fokker-Planck equations. The detailed shape of the electron velocity distribution function was found to remain Maxwellian under the influence of the inelastic term for typical coronal conditions.

The second application of the calculations pertained to the fast magnetic compression theta-pinch experiments, where extreme non-equilibrium conditions are known to exist. Because of the heating mechanism, the ion velocity distribution function is initially gaussian-centered at non-zero velocity, while the electrons are initially Maxwellian. Previous workers have assumed, incorrectly, that because of the time scales involved, distribution functions would remain unchanged during the plasma lifetime. However, these detailed calculations showed very significant changes due to interaction of non-equilibrium distribution of functions. These interactions, in turn, produce strong changes in the neutron yield, and in the shape of the free-free and free-bound continua, during the plasma lifetime.

Transition Probability Calculations

Intermediate coupling transition probability calculations have been carried out by House for the configurations $2s^22p^2 - 2s2p^3$ in Ca XV and for $3s^23p^2 - 3s3p^3$ in Fe XIII. Significant departures from L-S coupling give, in many cases, transition probabilities in normally forbidden lines, comparable to those which would be allowed in L-S coupling. The wave functions for the calculations were obtained from a Hartree-Fock program loaned to us by Dr. Charolette Froese (University of British Columbia).

SHOCK TUBE STUDIES

Nakagawa began an experimental investigation of relaxation phenomena under non-LTE conditions, with a co-axial plasma accelerator (the "plasma gun"). The plasma gun accelerates a current sheet (an ionized gas which carries the current) through the Lorentz acceleration, by the interaction between the self-induced magnetic field and the current; the current sheet, after leaving the gun, acts as a piston and produces a shock wave in the gas in the shock tube.

High-purity hydrogen, of the initial pressure 500 m torr, was used in experiments, and time-resolved spectroscopic observations were made with photomultipliers for two continuum emissions at both sides of the Balmer limits and for line emissions of the Balmer series, such as H-α, H-β and H-γ. Spectroscopic data were reduced to final physically meaningful quantities by the 6600 computer, utilizing a computer program developed by Vasicek and Wolf.

The computer program for data reduction consists of the following five steps:

1) determination of electron temperature from the ratio of two continuum emission intensities;

2) determination of electron number density from absolute continuum intensity;

3) determination of occupation number density for the various electronic states, using the results of (1) and (2) through statistically steady-state rate equations developed by House for hydrogenic line emission;

4) determination of occupation number density from absolute line intensity of experimental data, after performing necessary corrections for line profiles; and

5) comparison of results of (3) and (4).

Particular attention was paid to correction of line profiles; the program includes corrections due to Stark and doppler broadenings.

General agreements between the two different determinations of occupation numbers were found with the assumption of complete opacity for the Lyman lines and Lyman continuum emission. However, detailed analyses indicated that although an excellent agreement always exists between the line and continuum data approximately 2 μsec downstream behind the shock, a difference of a factor of 2 to 5 exists earlier in the shock. The latter discrepancy cannot be interpreted in terms of microscopic non-LTE, where the transition probability demands relaxation time of the order of 10^{-8} sec. Only a macroscopic non-LTE, i.e., a turbulence or a spatially inhomogeneous shock front, would explain this discrepancy. This conclusion requires us to re-examine the co-axial gun performance and to study the stability of shock front and its structure.

Vasicek has also performed some preliminary experiments on the stability of the boundary between a magnetic field and plasma flow (the boundary between a current sheet and a magnetic field somewhat analogous to the magnetopause boundary), to determine the necessary requirements of instrumentation for later experiments. He used the rather uniform plasma flow which occurs 2 μsec or more behind the shock front, and observed the formation of a boundary, and deformation of this boundary by instability. He found that a uniformly flowing plasma of temperature $\sim 10^4$ °K and velocity $\sim$30 km/sec for the time duration of 40 μ sec can be used for this experiment.

The theoretical study of a radiative fluid flow under non-LTE, reported last year, has been continued by Nakagawa and Wu. This study was an attempt to bridge the gap between a non-LTE description and a continuum description of the problem. In order to keep the problem as general as possible, and avoid unsolvable complexity, a weakly ionized hydrogenic plasma composed of electrons, ions and neutral atoms was considered, and the resultant macroscopic equations were derived up to the Navier-Stokes order of approximations.

Resulting equations include all the effects of macroscopic non-LTE (i.e., with different mean velocities and temperatures for each different constituent species) and space inhomogeneity to the first order, with appropriate macroscopic transfer coefficients, as well as the effects of cross-relaxation, radiation, and ionization.

MT. EVANS LABORATORY

In recent years, there has been a growing conviction among some high-energy physicists that, with the use of modern techniques developed in connection with accelerators, cosmic rays can again be a fruitful source of quantitative information about elementary particles. Of course, a small group of particle physicists has been utilizing cosmic rays as a "beam" for studying very high energy phenomena. However, the number of real advances that have been made in our understanding of very high energy phenomena has been quite limited. Progress has been general rather than specific, as, for example, in studies of multiple meson production proportion of non-pions to pions, transverse momentum distribution, and variation of multiplicity with energy. Most of these phenomena have been determined qualitatively rather than quantitatively.

We now possess techniques suitable for obtaining quantitative information about elementary particles. In 1965 a preliminary study was begun by a group of physicists from various institutions, under the leadership of Lawrence W. Jones of the University of Michigan, to ascertain whether useful work with cosmic rays can really be done. If the techniques prove to be successful, an inter-university or national mountain-top laboratory will probably be established, equipped for a massive attack on problems involving the interaction of particles in the hundreds of Bev range. Mt. Evans is being considered for the site.

Although such a permanent facility would primarily interest high energy physicists concerned with the physics of elementary particles, it might also be equipped for the study of problems related to the sun, astronomy, cosmology, and the atmosphere.

We feel that NCAR should be alert to the possibilities presented by such a mountain-top station, accessible from Boulder and considerably higher than our Climax station. Furthermore, although we generally think that studies of the solar and terrestrial atmospheres and interplanetary space do not involve nuclear or fundamental particle interactions, such is not always the case. The overlap of the two fields is shown by evidence from recovered satellites of emission from a flare of particles which could most reasonably be explained by nuclear processes in the flare itself, and by the recent search for distorted emission lines in the ultraviolet spectrum of the sun resulting from the attachment of the postulated quark particles to atomic nuclei.

During the year Bussian joined the staff to work full time at the Mt. Evans Laboratory and to participate in cooperative experiments under way at that site.

Experiment of 1965 and 1966

The first Mt. Evans experiment, begun in the summer of 1965, was greatly expanded in the summer of 1966 and continues at the end of the report year. The purpose of the experiment is two-fold: to test apparatus modeled after that required in a proposed permanent cosmic ray experimental facility, and to search for the postulated quark. The apparatus being used at present consists of five basic components: proportional counters, a spark chamber, a total absorption spectrometer, an array of shower counters, and electronics. If the quark exists in a stable state it is expected to have charges of 1/3 and 2/3 e and a mass of at least five times the nucleon mass.

When a high-energy, strongly interacting particle enters the atmosphere, it will most likely interact and create a shower of high-energy, low-mass particles (electrons, muons, pions) which will travel at very nearly the speed of light. In addition, one or more particles with higher mass (nucleons, nuclei, quarks, etc.) will be formed. If one of these heavy particles enters the spectrometer and has an energy greater than 50 Bev, it is classified as an interesting event. The time difference between arrival of this particle of interest and the associated shower is given by,

$$\tau = 3.3\, z\left(\frac{1}{\beta} - 1\right) \times 10^{3} \text{ nsec}$$

where

z = distance (in km) above apparatus where shower particles and heavy particles were produced

$$\beta = \frac{\text{velocity of particle}}{\text{velocity of shower} \simeq c}$$

For a known energy (measured by the spectrometer), the delay time depends only on the mass of the particle; i.e., higher mass corresponds to greater delay time. Thus, in the search for quarks, one looks at events with large delay times. By using proportional counter information, the charge of the particle can be determined.

Results from 1965 showed no evidence for quarks. Analysis of the 1966 data has not been completed.

STARS

STABILITY OF STARS

Durney has continued his study of the marginal instabilities of non-radial oscillating, slowly rotating polytropes, started in England in collaboration with I. Roxburgh. For marginal instability (zero pulsation frequency) the linearized equations of motions for these non-radial oscillations can be solved only for certain values of the ratio of the specific heats. These values are determined as the eigenvalues of two coupled partial differential equations relating the radial displacement and the perturbed pressure. The method used to solve this problem was to expand all quantities in spherical harmonics; an infinite number of coupled differential equations are obtained. In the first approximation all spherical harmonics except the lowest were neglected; higher order spherical harmonics were retained then in the higher approximations. Interpretation of results leads to the conclusion that rotating polytropes are unstable against non-radial oscillations.

THE UPPER ATMOSPHERE

GEOMAGNETISM, THE IONOSPHERE, AND THE MAGNETOSPHERE

During 1966, ionospheric currents, sporadic E, and geomagnetic micropulsations were studied by Matsushita, Reddy, and Saito. The purpose of these studies in apparently different fields was to discover interactions between the ionosphere and the magnetosphere and between the ionosphere and the mesosphere, by combining all results obtained for each phenomenon. For example, ionospheric currents may give information on distribution patterns of electric fields (related to magnetospheric distortion) and of tidal winds related to mesopheric tidal motions. Wind shears and gravity waves estimated from sporadic E may also show a connection with mesospheric motions. Charged particles deduced from high-latitude sporadic E suggest behavior of the magnetosphere over the earth's polar regions. Micropulsations indicate ionospheric oscillations and hydromagnetic-wave propagations in the magnetosphere. The final goal of the present projects is to obtain a general picture of the dynamics involved in the earth's upper environmental region.

Ionospheric Currents

Ionospheric current patterns in high latitudes on low Kp days were estimated by Matsushita from all available IGY geomagnetic data (obtained at 25 stations in the northern hemisphere and 14 stations in the southern hemisphere). The current systems obtained indicate that, even on low Kp days, incoming particles from the magnetosphere produce a "quiet-day auroral zone" in each hemisphere. These zones are located at higher latitudes (L = 20 earth radii line at 100 km altitude in the daytime and L = 7 earth radii at night) than disturbed-day auroral zones. In addition, distributions of local K-index values obtained by Matsushita, occurrences of pc 5 and pi 2 pulsations obtained by Saito, and fbEs occurrence distributions obtained by Reddy give a general picture of the interaction between the magnetosphere and the ionosphere over the polar regions on low Kp days, as is shown in Fig. 5.

Matsushita calculated electric field distributions for Sq and L current systems available, basing his calculations on various models of electric conductivity. His results are useful for the estimation of tidal wind patterns and for the discussion of electromagnetic drift effects on the ionosphere and the magnetosphere. Matsushita also theoretically predicted the November 1966 eclipse effect on the equatorial electrojet. Studies of geomagnetic records obtained by Tanton and others at Jicamarca near Lima, Peru for that event are in progress.

Sporadic E

The wind-shear theory of sporadic E (Es) has provided a major advance in theoretical understanding of Es; at the same time it has created a definite need for new and well designed morphological studies of Es to test its main inferences. Matsushita and Reddy have completed a detailed world-wide study of mid-latitude Es in the light of the wind-shear theory of Es. The wind-shear theory predicts the formation of thin layers in the E region; these thin layers correspond to the blanketing type of Es observed at middle latitudes. By choosing the blanketing frequency, fbEs, as the basic Es parameter, they have avoided many limitations of earlier statistical studies on Es in which foEs or fEs was used as the relevant parameter. The hourly values of fbEs obtained at over 80 stations in 1958 have been statistically analyzed to yield latitudinal, seasonal, and diurnal variations of fbEs and of the occurrence frequency of fbEs $\geq$ 2.0 Mc/s. Results show that fbEs varies on the average, in step with foE (the critical frequency of the E layer) in all seasons at all latitudes, suggesting a strong dependence of fbEs on the local foE value during daytime. The occurrence frequency of Es shows two daytime maxima in local summer and a single afternoon maximum in local winter; further, it exhibits a rather complex latitudinal variation and many

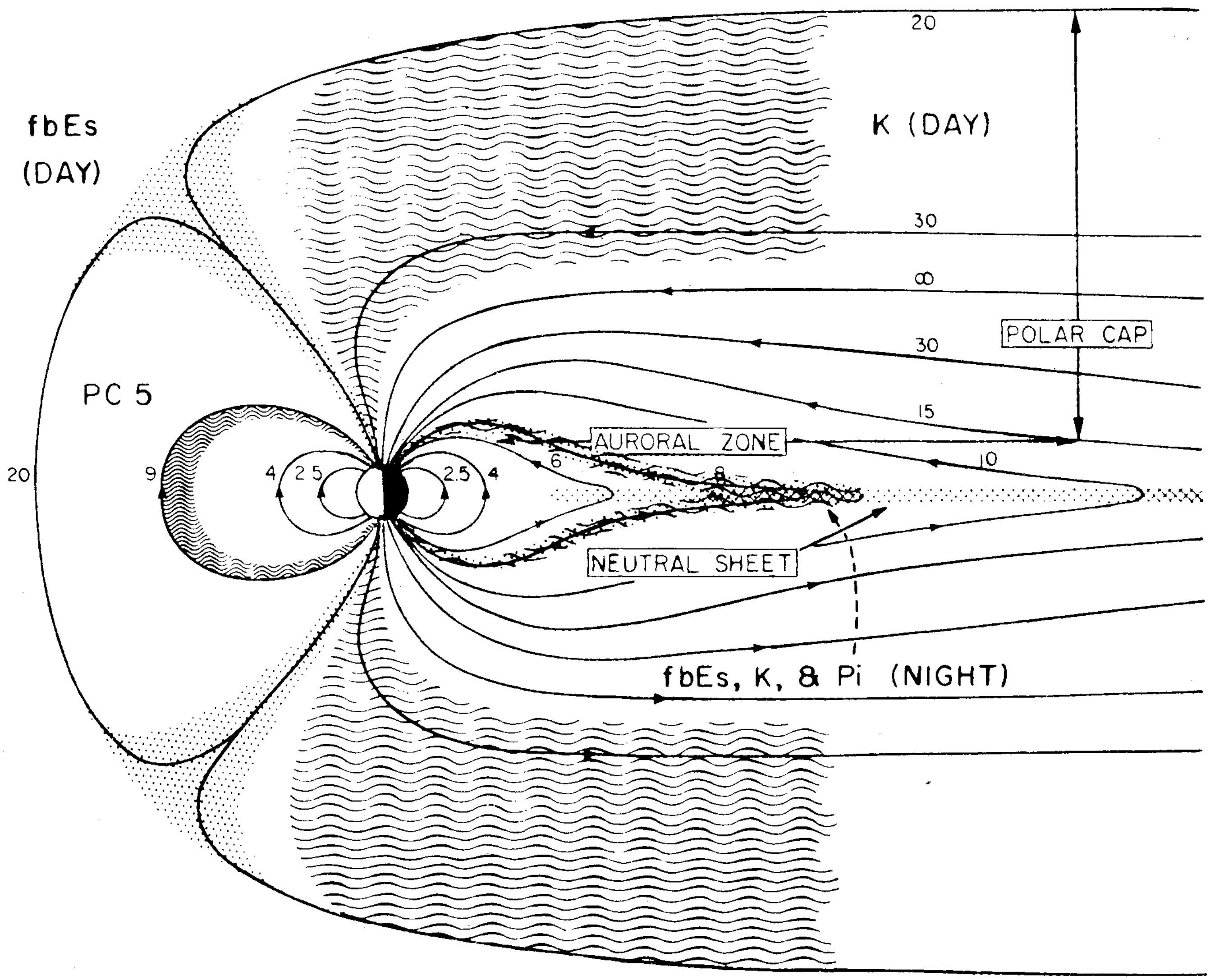


Fig. 5 Interaction between magnetosphere and ionosphere on quiet (low Kp) days. Numbers near the earth's magnetic field lines show undisturbed L shell values in the unit of the earth's radius at 100 km altitude.

On the day side, particles (dots) penetrate along L = 20 lines into the ionospheric E region and cause sporadic E and day-side polar-region currents. Hydromagnetic waves (fine wavy lines) along L = 8 to 9 lines cause pc 5. Irregular plasma fluctuations (large wavy lines) in the zone of L = 20 to 50 lines cause geomagnetic disturbances, hence large K-index values, on the day-side polar region.

On the night side of the earth, particles and hydromagnetic waves (dots and wavy lines) from the neutral sheet (cross-hatched lines) in the magnetospheric tail cause the Es, large K values, pi pulsations, and night polar-region currents. Even on low Kp days these disturbances occur in the polar region.

irregular fluctuations. All the morphological features of blanketing Es during daytime can be explained with wind shears as causative agents. In particular, we conclude that the blanketing frequency of Es layers depends primarily upon the background E-region ionization, whereas the occurrence of Es reflects the complexity and variability of wind shears in the E region.

The incidence of Es at high latitudes is believed to be caused by the precipitation of energetic particles into the lower ionosphere. Matsushita and Reddy are constructing spatial and temporal patterns of Es incidence at high latitudes for both magnetically quiet and disturbed periods. By comparing these patterns with experimentally obtained patterns of particle fluxes of various energies, it is possible to identify the particle fluxes responsible for the production of high-latitude Es. Results already show that Es incidence is closely related to incidence of intense auroral forms. This study will be completed shortly.

Matsushita and Reddy have recently initiated a new study on the relationship of sporadic E activity with solar cycle. This has been an elusive aspect of sporadic E behavior, giving rise to conflicting and inconclusive results in many earlier studies. The present study, based again on the choice of fbEs as the relative parameter, has already given some encouraging results. The blanketing frequency, fbEs, shows a clear positive correlation with sunspot number, as is to be expected on theoretical grounds. A detailed study aimed at finding a definite answer to the question of dependence of Es on solar activity is in progress.

Micropulsations

In order to investigate one aspect of the physical behavior of the earth's magnetosphere, Saito analyzed the data of geomagnetic pulsations which are thought to be due to hydromagnetic waves propagating in the magnetosphere.

Through the courtesy of W. H. Campbell (Institute for Telecommunication Sciences and Aeronomy, ESSA) a new technique of dynamic spectral analysis was applied to data of pulsations observed at ESSA stations. Spectra of wide period range ($0.2 \simeq 500$ sec) covering all seven categories of pulsations (pc 1, 2, 3, 4, 5, pi 1 and 2) were obtained by this technique.

Saito and Matsushita studied pi 2 (damped pulsations with the period of about one minute) which often occur at night. Based on the data obtained at two middle-latitude stations, Fredericksburg and Onagawa, during the past ten years, solar-cycle effects on these pulsations were found. An occurrence model of these pulsations was discussed in relation to an instability of the magnetospheric tail.

Saito and Matsushita also analyzed damped pulsations associated with all sudden storm commencements and impulses which occurred during seven years from 1956 through 1962. These damped pulsations, psc, show characteristics which are very similar to those of the so-called continuous pulsations, pc. The similarities suggest that oscillative systems for hydromagnetic waves always exist in the magnetosphere.

OZONE

During the past year, London continued studies of the expected variation of total ozone during a solar eclipse. These studies, besides being of general theoretical interest, were conducted in preparation for two observing programs during the South American eclipse on 12 November.

The first program involved observations of total ozone, using a ground-based Dobson spectrophotometer at the Geophysical Observatory at Huancayo, Peru. The expected (theoretical) variation of total ozone above the observatory is approximately 1%. Since this is slightly less than the limit of absolute accuracy of the instrument, a careful program was developed to determine relative variations of total ozone during the eclipse. Solar limb-darkening corrections for the wavelength pairs of importance in the observational technique had to be determined from theoretical and empirical considerations. These were incorporated in the data evaluation program. For the eclipse observations, the University of Colorado cooperated with the Geophysical Institute at Huancayo, and a former student in the Department of Astro-Geophysics, A. L. Snyder, Jr., spent one week at the eclipse site prior to and during the eclipse. On the eclipse day the sky was overcast with cirrus clouds and observing conditions were only moderately good. Preliminary data evaluation indicates that there probably was no large (> 5%) ozone variation during the eclipse, but further analysis will be required to determine the upper limit of possible variation.

A second observing program, one in which NCAR, Naval Ordnance Test Station (NOTS), and University of Colorado cooperated, involved floating a constant-level balloon at 33 km in the eclipse path, with an optical ozonesonde, designed by A. J. Krueger of NOTS, to measure total ozone variation above this altitude. Although expected (theoretical) variation above 33 km is of the order of about 8%, this is also the experimental accuracy of the instrument. Again, relative variations during the eclipse were sought, rather than absolute amounts.

Unfortunately, weather conditions at the site (rain and high winds) prevented the successful completion of this program, and the sparse data are extremely doubtful. However, this method is potentially useful for observing some aspects of the chemical kinetics of the stratosphere and mesosphere, and we hope that a similar experiment will be attempted in the future.

During the summer London and Irene Marenin (University of Indiana) conducted a pilot research program on space and time correlation of ionization in the D region. The purpose of the pilot study was to obtain knowledge which could be used in investigating vertical coupling between the stratosphere and mesosphere, but they found that the ionospheric data were not representative enough to be used as a parameter for the projected study.

CLOUD ALBEDO

The albedo for solar radiation incident on horizontally uniform, plane parallel clouds has been computed by several authors, notably Fritz, Korb, and Moller and Irvine. Their analyses are in general agreement on the dependence of albedo on the angle of incident solar radiance, optical thickness of clouds, and the albedo of the underlying surface.

The upper surfaces of most horizontally stratified clouds and fogs display varying degrees of texture caused by convection. James A. Weinman, visiting scientist from the University of Wisconsin, and Swartztrauber of the FAL Computing Facility, conducted a theoretical investigation to ascertain the influence of horizontal inhomogeniety in optical thickness on the albedo of stratified clouds. Their analysis was developed from a procedure employed by Giovanelli some years ago to investigate radiation emitted by granular convective cells of the solar photosphere.

The analysis assumed that a plane parallel, striated medium was externally illuminated by unidirectional incident light. The drops comprising the cloud were assumed to scatter light isotropically. The underlying surface was assumed non-reflecting, and no diffuse light was assumed incident on the upper surface of the cloud. The optical thickness of the cloud was assumed to vary periodically in the horizontal direction.

The analysis provided the following conclusions:

- A cloud with small-amplitude striations has a mean albedo independent of the amplitude of striations in the optical thickness of the medium. The albedo computed for a homogeneous medium is thus identical to the albedo averaged over a horizontal striation.

- The mean value of the albedo averaged over a striation is independent of the wavelength of the striation for striations of any amplitude.

• The contrast in albedo between optically thick and thin regions of the stratified medium decreases as the optical thickness of the cloud increases, and as the wavelength of the horizontal striations decrease. The reason for the decrease in contrast with increasing thickness is that the albedo of a cloud becomes less sensitive to any change in optical thickness as the cloud becomes thicker. The contrast dependence on horizontal wavelength is evident from the following reasoning: If the striation varies slowly in the horizontal direction, then light is scattered back out of the cloud before it is scattered horizontally into a region of different optical thickness. The contrast in albedo thus varies faithfully with variations in optical thickness. If, however, the horizontal striations have a short wavelength, light may traverse several striations before being scattered back out of the cloud. This smooths the effect of the striations, thereby reducing the contrast in albedo.

• Some of the computed values of albedo were physically unreasonable. The present analysis therefore provides some insight into the limitation placed on Giovanelli's approximation to the equation of transfer in heterogeneous media. This insight may also prove to be beneficial to solar astrophysicists wishing to apply that theory to granules in the photosphere.

SOLAR DATA REPORTING

Reporting of solar data by the High Altitude Observatory and the World Data Center followed the same general lines as those of previous years. The reporting was supervised by Trotter, assisted by LaVelle until her resignation the middle of September, at which time her duties were taken over by Snook and Gay.

We continued to issue, every Friday, the Preliminary Report of Solar Activity. In it we compiled and mapped available solar and related terrestrial data for the week. The Institute for Telecommunication Sciences and Aeronomy, ESSA, with its world-wide daily collection, was the main source of data, but these were supplemented by reports from our Climax station, from Sacramento Peak Observatory, and from the University of Colorado's radio spectrograph. The weekly report was distributed to 410 persons throughout the world.

Coronal indices of the $\lambda 5303$ and $\lambda 6374$ emission lines were computed for monthly publication in ITSA Solar Geophysical Data, Part B. For the year we computed integrated indices of the corona and published them in the HAO report series, and isophotal contour maps of the $\lambda 5303$ coronal emission line were published in the IAU Quarterly Bulletin of Solar Activity.

The operation of the World Data Center involved archiving data and publishing reports in response to international commitments undertaken during the IGY and continued through the IQSY and beyond. While future international obligations are being discussed at the end of the report year, certain steps have been taken to simplify the national problem of data archiving. In particular, ESSA has undertaken, under the direction of the National Academy of Sciences, to develop a consolidated data center covering a number of solar-related disciplines.

Although various committees studying the data problem were not able to recommend a completely logical consolidated center (for example, the geomagnetic data center remains a separate collection), a number of subjects will be represented in the new center in the ESSA laboratories in Boulder, including solar activity. A schedule was worked out during the year, therefore, for phasing out HAO World Data Center activities and the transfer of this work to ESSA, and the transfer was essentially completed by the end of the year.

CLIMAX OBSERVING STATION

A new approach to the management of the Climax Observing Station was instituted during the year in an attempt to integrate the work at Climax more closely into the scientific programs under way in Boulder. The position of Observer-in-Charge was abolished, and the job of Climax management was assigned as the prime responsibility of a member of the scientific staff in Boulder. This scientist divides his time between Climax and Boulder as the need requires. In addition, steps were taken to lessen the number of purely administrative and site-maintenance questions brought to the Scientist-in-Charge for solution.

SMALL DOME

The 5-in. coronagraph-spectrograph system had been seriously neglected during installation and development of the 16-in. system, so that various defects of alignment and adjustment, and improvised modifications had accumulated. During the summer, Rush worked through this system in detail, restoring adjustments and making improvements wherever feasible.

Lately we have also begun a renovation of the H-α camera system. The immediate effort on both of these systems has been to put them in optimum adjustment. We are now beginning a more deliberate program of improvements, principally through the replacement of low-quality optics with designed units. Some mechanical improvements also will be included as time permits. The systems on the small spar are inherently capable of excellent work for many purposes, and are far "handier" to use than the more capable but far more complex and cumbersome 16-in. system.

Spectroscopic observations of prominences, active regions, and flares have continued. The observational program of spicules, requested by Dr. R. J. Bessey of the University of Wyoming, is still in operation.

Development work continues on the search for better and faster ways to obtain spatially integrated spectra of the sun's disk in the light of H and K.

A new program of flare observation has been initiated at the request of Dr. De Feiter, Sacramento Peak Observatory, in cooperation with Curtis. It consists of obtaining limb flare spectra in the two regions H-β (3970A) to the Balmer limit (3646A) and 8500 to 9000A. A radial slit is used to obtain synchronous height resolution, and a time resolution of a minute or less is sought.

A joint calibration program between the two small coronagraphs of Sacramento Peak Observatory and Climax has been started, in order to discover the cause of past discrepancies in coronal data obtained with the two instruments and to bring their calibration into better agreement. Finally, a systematic evaluation of instrumental polarization in both coronagraphs has been started at Climax.

LARGE DOME

Early in the year, the film transport unit for the spectrograph, a focusing eyepiece, H-α slit monitor system, data panels, and raster scan for the guider lens were installed on the 16-in. system. These units essentially completed the system as planned. Rush has devoted a major part of his time to adjustment and testing of these units, and to various small refinements that add to the convenience and effectiveness of the instrument.

Performance of the system is good, both on film and in double-pass to the magnetograph. Weather has frustrated early attempts to measure the scatter background in the coronagraph, but the coronal spectra obtained indicate that it is quite low. The parallactic focusing eyepiece, adapted from John W. Evans' design, is practically indispensable in the operation of the spectrograph. It makes possible precise operational focusing of the spectrum on the film, to compensate for any slight deviations caused by grating imperfections or other factors; and it provides a similarly quick and exact check of focus of the solar image on the slit, and of the occulting edge in a chosen wavelength, thus solving what we had regarded as the most difficult problem in the entire system.

The scheme of moving both slit and collimator mirror axially to place the slit at the solar focus, while maintaining slit-to-collimator distance by a servo loop, was accepted as a necessary evil only because no better method of focusing appeared possible. However, this mechanism is entirely satisfactory in practice, and a differential Selsyn unit in the servo loop permits variation of the slit-to-collimator distance over a small range to compensate any slight focal deviation at the film.

We are now quantitatively evaluating performance and refinements of calibrations and some details of the mechanisms, as opportunity permits.

Two main research programs are now in operation with this instrument: observation of the continuum beyond the Balmer limit in prominences, and observation of the helium emission line spectrum of prominences. Spicule observations in H and K are now being attempted, combining the greater spatial resolution of the large instrument with a dispersion of 3 A/mm. A high time resolution study of a few coronal lines (5303, 6374 and hopefully 3388) in that portion of the corona above an active region is being attempted; we hope here to achieve a history of such regions before, during and after a flare occurs underneath. A high dispersion study of the sodium D lines in and outside of active regions is also being undertaken.

For two months during the summer Dr. David Wilkinson of Princeton University used the Climax site for microwave measurements. These measurements were an attempt to observe the weak, isotropic radio emission predicted on the basis of a nuclear origin of the universe. The Climax site provides the low water vapor necessary for satisfactory measurements at millimeter wavelengths.

MISCELLANEOUS ACTIVITIES

BOOKS AND REVIEWS

Two books were published during the year based on work begun at the High Altitude Observatory but completed elsewhere. Donald E. Billings, of the University of Colorado, began his A Guide to the Solar Corona (Academic Press) while a staff member of the Observatory.

The Solar Atmosphere (Blaisdell Publishing Company), by Harold Zirin, was completed after Zirin assumed his present position at the California Institute of Technology. He left the Observatory in 1964.

Tandberg-Hanssen completed the manuscript of Solar Activity and publication is tentatively set for July 1967 (Blaisdell Publishing Company). The book treats the different manifestations of activity on the sun in a unique framework: as the inevitable results of interaction between solar magnetic fields and solar plasma. The treatment is both observational and theoretical; the book aims at a physical understanding of solar activity, which is achieved in two steps. First, the different models proposed to account for a given set of observations are discussed, then theoretical interpretations and speculations are presented.

Newkirk prepared a comprehensive review, "The Structure of the Solar Corona," for Annual Reviews of Astronomy and Astrophysics.

Matsushita, with W. H. Campbell of ESSA, has edited a book, Physics of Geomagnetic Phenomena, which is tentatively scheduled to be released by Academic Press in April 1967. Matsushita has contributed two chapters entitled "Solar Quiet and Lunar Daily Variation Fields" and "Geomagnetic Disturbances and Storms." The book attempts to consolidate reports of recent advances in geomagnetism and geomagnetic field phenomena, summarizing the present understanding of the physical scientists. It will serve as a resource to established physicists as well as to the increasing number of students in upper atmospheric and space topics.

Rust completed his thesis work at the High Altitude Observatory and was awarded a Ph.D. degree by the University of Colorado. His thesis was entitled Measurements of the Magnetic Fields in Quiescent Solar Prominences.

HIGH ALTITUDE OBSERVATORY PERSONNEL, 1966

DIRECTOR

John W. Firor

SCIENTIFIC STAFF

Martin D. Altschuler
R. Grant Athay
Sydney Chapman (combined appointment with the University of Alaska) (transferred to ASP, 1 May 1966)
G. William Curtis (from 18 April 1966)
Bernard Durney (on leave from 1 January to 1 September 1966)
John A. Eddy
Richard T. Hansen
Lewis L. House
J. McKim Malville
Sadami Matsushita
Yoshinari Nakagawa
Gordon A. Newkirk, Jr.
Joseph H. Rush
Andrew Skumanich
Einar A. Tandberg-Hanssen
Dorothy E. Trotter

VISITING SCIENTISTS

S.-I. Akasofu (17 July to 15 August 1966)
Alfred E. Bussian (from 10 August 1966)
Peter A. Gilman (25 July to 31 August 1966)
Thomas B. Gray (from 1 September 1966)
Peter C. Kendall (14 July to 16 August 1966)
Max Kuperus (from 17 October 1966)
Julius London (15 June to 2 September 1966)
C. Abhirama Reddy
Takao Saito
James A. Weinman (6 June to 26 August 1966)

CLIMAX STAFF

G. William Curtis, Scientist-in-Charge
Douglas Daniels (7 June to 26 August 1966)
Heinz Eichenseer (to 14 October 1966)
Charles D. Evans
Francis J. Gates (29 August to 15 December 1966)
Helen P. Glasco (from 27 September 1966)
Mary L. James (to 25 March 1966)
Robert B. James, Station Manager (transferred to LAS, 1 April 1966)
Ivan A. Lee (from 21 November 1966)
David M. Lesh (from 19 September 1966)
Werner H. Lindscheidt
Chester B. Porter
Patricia Rogers (from 8 August 1966)
Stephen R. Rogers
Angelina Sanchez
Juan F. Sanchez
Marilyn Shelley (7 March to 15 August 1966)
Robert D. Shelley (to 16 September 1966)

RESEARCH ASSISTANTS

Karen S. Canfield
Constantine G. Cassapakis (6 June to 31 August 1966)
Astrik Deirmendjian
Benedict A. Domenico (from 7 June 1966)
Charles J. Garcia
Marjorie E. Gay (from 1 September 1966)
Carol W. Gilmore (from 13 January 1966)
John E. Goff
Shirley Hansen
Mary M. Hilty
Harrison P. Jones (6 June to 15 September 1966)
Dale W. King
Margaret A. Koontz (13 June to 25 August 1966)
Ronald C. Kwon (20 June to 9 September 1966)
Kathryn P. LaVelle (to 15 September 1966)
Carl G. Lilliequist
Fred L. Lohndorf (to 2 June 1966)
Kathryn McKean
John McKinnon (20 June to 9 September 1966)
Irene Marenin (17 June to 23 August 1966)
Jon P. Okada (20 June to 13 September 1966)
Nicholas M. Perry (from 12 October 1966)
Richard M. Perry (20 June to 20 September 1966)
Charles L. Ross
William B. Sanborn
Virenda Saxena (to 31 January 1966)
Florence M. Scohy (to 31 May 1966)

Charles M. Smythe (13 June to 9 September 1966)
Jean Snook
Dallas E. Tanton
John E. Tam (to 18 April 1966)
Mary C. Travis (to 16 September 1966)
Francois Ulam (to 21 January 1966 and from 29 September 1966)
Charles P. Wolfe

GRADUATE ASSISTANTS

Richard C. Altrock
Lorne W. Avery (from 10 September 1966)
Richard L. Blake
J. David Bohlin
Richard C. Canfield
Robert P. Davies-Jones (to 9 September 1966)
William A. Deutschman
Mark A. Gordon (to 8 March 1966)
John W. Harvey
William Henze, Jr.
Christopher B. Kaiser (from 1 July 1966)
Roger A. Kopp (from 1 September 1966)
Aharon Lavie (to 9 September 1966)
David M. Rust (to 5 October 1966)
Edward J. Schmahl (from 6 June 1966)
Steven A. Schoolman
J. Daniel Tarpley, Jr.
Daniel J. Vasicek (from 2 February 1966)
Randolph J. Wolf
Shi-Tsan Wu

ENGINEERING AND INSTRUMENTATION

Harold T. Braidwood
Gerry A. Damon (1 June to 18 August 1966)
Lendell W. Davidson (from 1 August 1966)
David E. Green (to 9 September 1966)
Robert G. Hanson
Howard K. Hull
H. David Hultquist (to 14 July 1966)
Philip S. Kuhn
Leon B. Lacey, Engineer-in-Charge, Machine Shop
Loren D. Laramore
Bryan R. Lee (20 August to 30 September 1966)
Robert H. Lee, Engineer-in-Charge, Electronics Shop
Frank L. Melchior, Jr.
Brian K. Peterson (21 February to 11 March 1966)
Bryan B. Southward
Curtis L. Sumners (from 20 June 1966)
Robert F. Wendler
Werner J. Windbergs
Clyde M. Wyman
Kent M. Zakrzewski (28 March to 31 October 1966 and from 7 December 1966)

ADMINISTRATION, OFFICE AND MAINTENANCE STAFF

Clara G. Callahan
Cynthia H. Croft (to 2 September 1966)
Gerry A. Damon (from 24 November 1966)
Nancy L. Edwards (from 13 September 1966)
Patricia P. Faulkner (from 23 May 1966)
Doris G. Fisher
Joyce L. Foster (from 16 November 1966)
Ruby L. Fulk
Barbara L. Hill (27 June to 23 September 1966, transferred to LAS)
Darlene A. Hulett
Florence C. Lister, Librarian
Lillian M. Nakamura (3 June to 31 August 1966)
Constance S. Simpson (to 20 May 1966)
D. Keith Watson, Assistant to the Director
Diana M. Wilt (from 1 September 1966)
Eileen R. Workman

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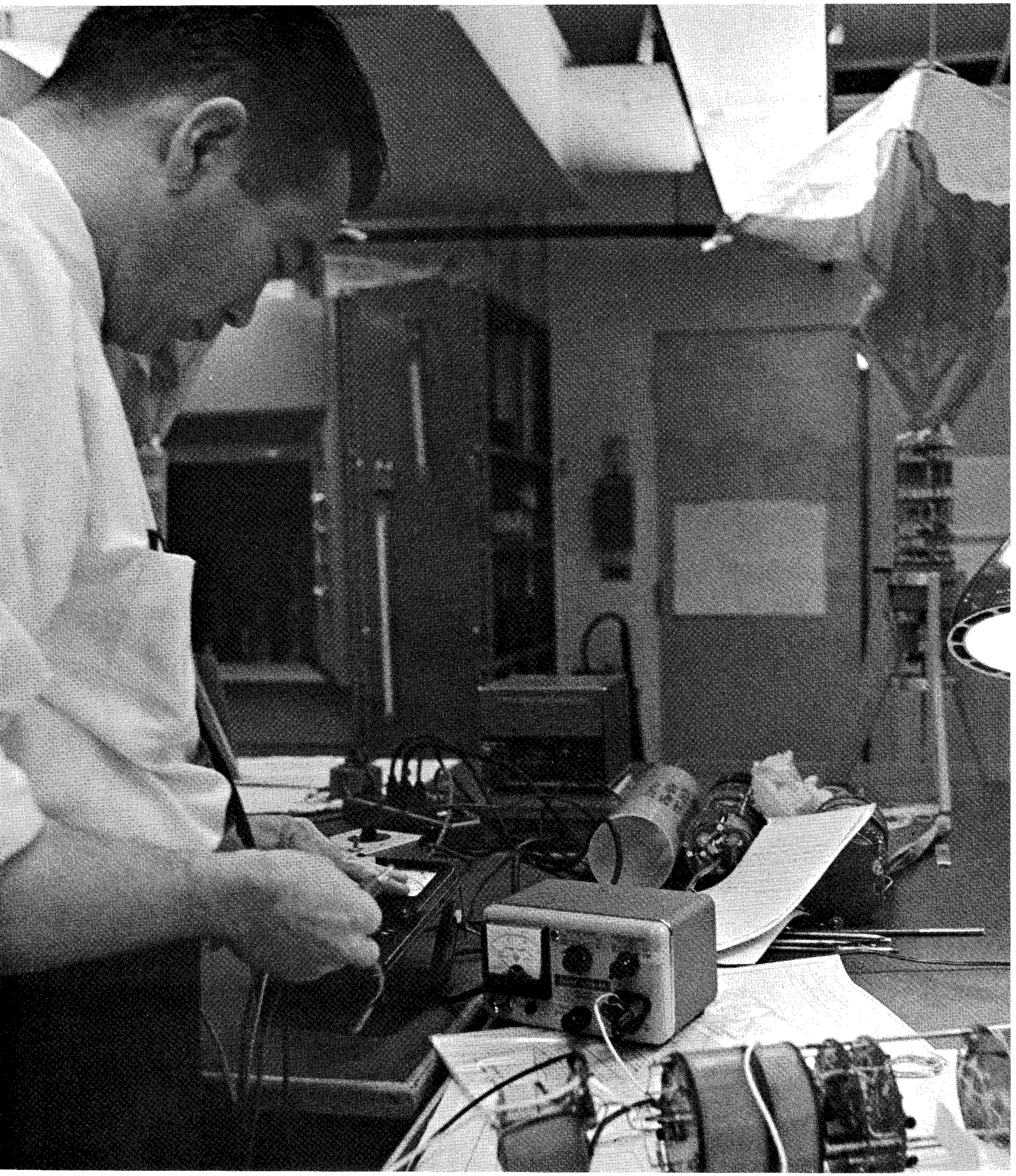
* Max Planck Institut für Physik und Astrophysik; scientific staff during 1965.
** Max Planck Institut für Physik und Astrophysik; scientific visitor during 1965.
*** King's College, University of London; scientific visitor during 1965.

Laboratory of Atmospheric Sciences



INTRODUCTION

"The Laboratory of Atmospheric Sciences (LAS) is a group of scientists and technicians devoted to improving man's knowledge of the earth's atmosphere -- and with more than a passing interest in the atmospheres of the sun and planets. The tools they use are those of the meteorologist, the physicist, the chemist, the mathematician, the engineer. Their particular advantage is that they have each other, and that they therefore have unusual opportunities to apply more than one discipline to a given problem" (1965 Annual Report).

The LAS is now about five years old, and for about three years has had more or less its present wide range of research activities. These span the fields of atmospheric physics and chemistry and include a large effort in atmospheric dynamics. All of these topics can be included in the subject of "meteorology" in its modern sense, although some of the work has involved exploring certain physical processes in depth, without much concern for their immediate atmospheric implications -- for example, the physics of ice formation, the theory of scattering of light, fundamental problems of convection and turbulence, etc. In LAS (and in NCAR) we adopt a broad definition of "atmospheric science."

The central objective of NCAR and LAS is to effect "major research achievements on the crucial scientific problems encountered in the atmosphere. Of special importance are those problems of large scale requiring investments of research talent and facilities beyond the capacity of individual scientists," and "possible only through creating and maintaining a research staff which sets a new high standard of quality in the atmospheric sciences."*

In the 1965 Annual Report we discussed some of our main human goals (improved weather predictions, weather and climate modification, and conservation of the atmosphere), and the broad problem areas that we were attacking to work toward those goals. The goals and problems remain with us. While the research continues, and depends on the individual scientist's ability, imagination, and dedication, the task of LAS as a whole and of its leaders is to assess continually the direction the research is taking, and to decide whether we are investing our research talent and facilities to best advantage.

Several current trends, both within NCAR and in the larger scientific world, have influenced the way we view our program. These are not sudden events, but have been brewing for a long time, and we have been aware of them from the start. We will describe some of them briefly; details of how they affect the research going on in LAS will be apparent in the individual reports.

Perhaps the most significant new factor in the world of meteorology is a growing optimism: we <u>can</u> learn to deal with the entire atmosphere as a system in which every part interacts with the rest. Complex as it is, this system must obey the laws of physics, and we are approaching the time when our theoretical and observational tools will be powerful enough to treat it realistically.

On the theoretical and conceptual side, the large computer is the tool that has allowed our theories to be applied to creating mathematical models of the general circulation of the lower atmosphere. NCAR possesses the most powerful generally available computer (the Control Data Corporation 6600), and in our dynamical program we are testing models of the general circulation and of convective systems of a complexity that would have made them almost inconceivable a few years ago.

* Appraisal of the NCAR Program: Report to UCAR Council of Members by the Committee on Evaluation and Goals, March 1966.

On the observational side, work in the Facilities Laboratory (FAL) of NCAR and elsewhere on the development of a global atmospheric observing system using constant-density balloons, automatic weather buoys, indirect sensing systems in satellites, etc., promises to give us a much more complete picture of the atmosphere as a whole than we now have. At present, less than 20% of the northern hemisphere is adequately covered with weather observing stations, and in the southern hemisphere the coverage is far less. We have no way, therefore, to test our theoretical models against the real atmosphere -- and, of course, no way to use these models to make better forecasts, either. It is the goal of the international scientific community (under the aegis of the International Council of Scientific Unions) and of the governments of the world (under the aegis of the World Meteorological Organization) to make some attempt at truly global observations in the early 1970s. NCAR and LAS are involved in this national and international program, and will be more so in the future.

A particular gap in our knowledge of the lower atmosphere on a global basis is the behavior of the vast areas of the tropical zone. These are sparsely furnished with regular observing stations, and few meteorological research organizations have had the interest and the resources to mount adequate programs of study in the tropics. Yet, the general circulation people see this zone as the major source of heat and moisture for the atmospheric "heat engine." Energy from the sun is deposited in the atmosphere primarily through exchange of heat and water vapor at the surface, combined with convection on a grand scale (great masses of thunderstorms) that transports this heat and latent heat to the upper troposphere. The general way in which convection acts in the tropics is becoming clear, but the details of its behavior are still mysterious -- and to be successful our general circulation models must incorporate these details.

Recognizing this meteorological gap in the tropics, NCAR held a series of meetings, starting in January 1966, to plan a long-term program of tropical meteorological experiments, called TROMEX. Taking part in this planning effort were university and government scientists and representatives. The result has been the skeleton of a long-range plan, and an immediate marshalling of forces by NCAR for a concentrated observing program in the region of the Line Islands, due south of Hawaii and directly under the first NASA synchronous satellite with a meteorological camera. Out of this Line Islands Experiment, to be conducted early in 1967, should come the first good observations in which tropical wind fields and convective cloud patterns are observed in a coordinated way, and from such observations there will be an opportunity to test hypotheses about how large-scale motions and regions of convection interact with each other in the tropics. This experiment involving a coordinated effort to observe a region of the tropics from land, sea, air, and space, is perhaps a pattern that NCAR will follow again many times, with FAL organizing logistics, NCAR and government agencies furnishing support, and LAS working closely with interested university scientists and providing scientific leadership (Edward Zipser is scientific coordinator of the Line Islands Experiment).

We noted above that there is a growing interest in treating the atmosphere as a whole, and this applies in the vertical as well as in the global sense. With rockets and indirect probes that can bring us more detailed information about the region above the ceiling of balloons (about 30 km for routine soundings), it is possible to test theories dealing with the dynamics of the upper stratosphere, mesosphere (50-80 km), and thermosphere (above 80-85 km). Some of these theories deal with influences that propagate upward (for example, Richard Lindzen's work on tides in the upper atmosphere) or that appear to propagate downward (as do the effects of changes in the ionosphere on the fair-weather electric field, being studied by Doyne Sartor, or the meteoritic dust which may form ice nuclei in the upper troposphere, being investigated by Jan Rosinski). Thus, several of our investigations, both observational and theoretical, are reaching upward to include the upper atmosphere and the possible effects of changes in the sun. This trend will, we hope, continue.

These efforts to study the global atmosphere are major ones, but they have not blinded us to the need for furthering our work on various phases of atmospheric chemistry and cloud physics, some aspects of which relate rather directly to the global circulation problem, anyway. In our efforts to understand air pollution and its effects we are studying the chemistry of the unpolluted atmosphere in several parts of the world, and we have three or four laboratory projects to define various chemical and photochemical reactions that are of importance in smog formation or in the chemistry of the upper atmosphere. Cloud physics -- the study of the origin of cloud particles and the formation of rain, snow, and hail -- is a subject that is being approached by several groups; and closely related to it is the study of dynamics of convection, since the motions in a cloud obviously help to determine what will happen to the cloud particles. In atmospheric science it is important to keep all scales of events in mind, from the atomic to the global -- indeed, even to the solar system.

In order to provide good communication between various LAS scientific programs and with the High Altitude Observatory we have a continuing series of seminars and colloquia, some regular, some on the spur of the moment. In dynamics and synoptic meteorology, such seminars date back to the time when the "theoretical types" were housed in Cockerell Hall on the C.U. campus, and are still referred to sometimes as "Cockerell Hall get-togethers." These have been organized by Douglas Lilly and Chester Newton. This year, after the move to the mesa, Julian Shedlovsky instituted a series for the chemistry and physics interests. In all these gatherings our visitors also play an active role, of course.

In September the LAS held its third annual retreat in Estes Park, where for two and one-half days we had a chance to talk with each other undisturbed by telephones. The central subject this time was cloud physics and convection. The purpose was partly to acquaint ourselves with the subject in some detail, under the tutelage of our experts in the field (plus Dr. M. H. Davis of RAND), and partly to decide on what the outstanding problems are. Both objectives were fulfilled to a large extent.

At the very close of 1966 a move was made, after much thought and discussion between the Director, the other Associate Directors, and myself, to create two departments in the LAS, one to include programs dealing with dynamical aspects of the atmosphere, the other dealing with micro-physics and chemistry of the atmosphere. Philip Thompson, Associate Director of NCAR and the first director of LAS, has agreed to head the former, and Richard Cadle will head the latter. The new arrangement will provide more scientific direction, and help to focus a part of our effort in LAS on additional major problems in the atmosphere that require a coordinated attack. We are already working in several major problem areas, as the reports below will indicate.

The discussion so far has dealt a great deal with the "big problems" in the atmospheric sciences and how they affect LAS. Problems that require a joint effort by many people are, to some extent, our stock in trade, but we will always maintain that our real value lies in the individual talent of our scientists, whether they are working on these major projects or doing creative work by themselves. It is the scientists who do the research, not the organization. In the reports that follow, the scientists themselves will speak.

William W. Kellogg
Director

ATMOSPHERIC DYNAMICS

The most obvious feature of our atmosphere (and it would be of the atmospheres of the other planets too, if we were in them) is its motion. The restless atmosphere moves across oceans and continents, and "weather" is largely determined by the moving air masses. Thus, the science of forecasting weather (it used to be referred to as an "art") is largely dependent on being able to predict what the patterns of motion will be a day, two days, three days hence. Look at a weather map: the isobaric or contour lines describe the wind field, and these, together with the fields of temperature and humidity and cloudiness, give the best picture of the atmosphere that we can draw.

It is not surprising, therefore, that a substantial part of the LAS research program is devoted to understanding atmospheric motions on all scales -- the dynamics of the atmosphere. The largest scale of motion refers to planetary wind fields at all levels, featuring the well known cyclonic and anticyclonic systems that tend to move from west to east or that remain stationary for periods of time. Taken together they define the general circulation. Smaller, meso-scales of motion are involved in hurricanes or typhoons, land-sea effects, mountain waves, etc.; a still smaller but very important kind of motion is convection caused by thermodynamic instability, which may produce rough air near the ground on a hot afternoon, or a towering thunderstorm. At the small end of the size scale of interest to us here are those aggregates of eddies that we refer to as "turbulence," where the energy of the larger eddies is constantly being converted to the energy of smaller eddies, until finally the energy is imparted to individual air molecules, and becomes "heat."

In order to comprehend the dynamics of the atmosphere in all its complexity one should deal with all these scales of motion at once, but this is impractical. It is an article of faith among dynamic meteorologists that the large-scale general circulation theory can treat the meso-scales of motion and turbulence as kinds of statistical effects, and that they can be described in the aggregate by a few parameters. This greatly simplifies their treatment, of course, and yet their role in transporting heat, moisture, and momentum is not neglected in the large-scale picture. (See the description of the general circulation model developed in LAS, p. 49.)

For other purposes, such as understanding how convection arises, how clouds are formed and why some grow while others dissipate, how mountain winds behave, why hurricanes grow, etc., it is necessary to concentrate on the meso-scales of motion and to neglect the large-scale effects. The limitations of our theoretical and computational tools restrain us from doing more.

In the sections that follow we will describe our studies of the general circulation and large-scale motions first, and then discuss studies of convection, boundary layer phenomena, turbulence, and other smaller scales of motion -- though such a distinction cannot always be made.

There are, generally speaking, two ways of studying the dynamics of the atmosphere that must go hand in hand: the theoretical approach, in which mathematical models or analytical relationships based on first principles are sought; and the synoptic approach, in which observations of the real atmosphere are pieced together to create a coherent picture. Since observations are almost never adequate, the synoptic meteorologist must have a firm background of theory in order to interpret what he sees and to fill the gaps. When he has finished he can present the theoretician with a framework in which mathematical models can be tested. As we have said, the two approaches must go hand in hand, and we will try to describe them that way.

LARGE-SCALE MOTIONS IN THE ATMOSPHERE

General Circulation Numerical Experiments

Since 1964 Akira Kasahara and Warren Washington have been working on the design of a mathematical model of the general circulation. Good progress was made during 1966. Reports in preparation will describe the basic framework of the model and the results of recent calculations.

A distinguishing feature of the NCAR general circulation model (three other groups in the U. S. are working along similar lines) is that the vertical coordinate is height rather than pressure, though hydrostatic equilibrium is maintained in the system. The use of pressure as the vertical coordinate is more common, since the continuity equation is reduced to a diagnostic equation. However, this advantage is offset by the disadvantage in handling the lower boundary conditions of the system, since the earth's surface hardly ever coincides with a constant pressure surface. To eliminate this difficulty, Phillips (1957) introduced the so-called "σ-coordinate system" which has been adopted in the Smagorinsky-Manabe (Smagorinsky, et al., 1965; Manabe, et al., 1965) and Mintz-Arakawa (Mintz, 1965) models. Leith (1965) uses pressure as the vertical coordinate. Some of the advantages of using height as the vertical coordinate are that the prognostic equations have simpler forms compared with those in the σ-system, and lower boundary conditions are more easily formulated.

The dynamic framework of the NCAR model is therefore very similar to the one proposed by Richardson (1922). Spherical coordinates are adopted, and the grid network covers the entire earth. The planetary frictional layer is included in the model by incorporating the horizontal and vertical eddy exchange processes for momentum and heat. The effects of the surface boundary layer are simulated by the lower boundary conditions of the model, which permit the evaluation of surface stress and of sensible heat transport from the earth's surface. Heating due to incoming solar radiation and cooling due to long-wave radiation are included in the model. The effect of continentality is reflected in the distribution of temperature which is prescribed in the input data, but orography is ignored in the first version of the model. A hydrological cycle is not calculated explicitly, but the effect of the release of latent heat of condensation is taken into account by assuming that the atmosphere is completely saturated by water vapor. However, the amount of latent heat release is adjusted by a factor which determines the rate of condensation. The effect of cumulus-scale convection is empirically included in this factor.

The present version of the model uses a grid network of two height levels plus the surface level, with a vertical spacing of 6 km, and covers the entire globe with a horizontal spacing of 5° in both longitude and latitude. Finite-difference equations are based on a modified version of the two-step Lax-Wendroff scheme proposed by Richtmyer (1963). (See p. 56 for further discussion of finite difference integration schemes.) A time step of five minutes is used. An isothermal atmosphere of 250°K is used as the initial condition. The distribution of sea-level temperature, the long-wave cooling rate, and the declination of the sun are prescribed for mean January conditions. It takes 30 to 40 days to establish flow patterns in the model atmosphere, and these patterns resemble the typical highs and lows of the real atmosphere, which result from baroclinic instability.

At present many short-term (10 to 30 days) and long-term (80 to 100 days) integrations are being made on the Control Data 6600 by changing the magnitudes of various physical parameters within their reasonable ranges. It is important to change only one parameter at a time, to see the response of varying the parameters in the model. This process is somewhat analogous to tuning a piano. The results of integrations are compared with climatological data of the atmosphere. Comparison data include zonal mean distribution of wind velocity components, and temperature and pressure in a meridional cross section. The magnitudes of various physical parameters in the model will be determined so that the selection of those values will give the best computed climatology compared with observed data.

The analyses of computer output are aided by the dd80, a visual data display unit attached directly to the Control Data 6600. Several motion pictures, both color and black and white, were made to illustrate the evolution of computed surface pressure distribution.

Real Data Forecasting

In order to verify predicted patterns computed by the NCAR general circulation model, plans are being made to use real atmospheric data for initial conditions and to compare forecast patterns with observed patterns. The present two-layer version of the model requires, in addition to sea-level pressure distribution, preparation of pressure fields at levels of 6 and 12 km, corresponding approximately to 500 and 200 mb, respectively. According to Roy Jenne of the NCAR Computing Facility, who has been in charge of collecting meteorological data, data of January 1958 may be the best for this purpose. Southern hemisphere latitude-longitude grid analyses from South Africa give surface pressure and 500-mb heights for the area of 15 to 80°S (at the surface) or 15°S to the South Pole (for 500 mb). No analyses are generally available for 200-mb heights. Northern hemisphere National Meteorological Center octagonal grid analyses give surface pressure and 500-mb and 200-mb heights. Data between 25°S and 25°N are obtained from World Weather Maps, IGY 1957-1958, published by the German Weather Service.

Harry van Loon has prepared 200-mb height analyses in the southern hemisphere for the period 15-19 January 1958. (See p. 54 concerning southern hemisphere.) Forecasts based upon such synthesized analyses may not be adequate for verification of a general circulation model; however, experience gained in preparing them will be worthwhile, since we expect to obtain more complete data in the future. Placido Jordan is compiling data from these sources on punchcard forms.

With respect to the use of real data, David Houghton and Warren Washington are working in collaboration with Akira Kasahara on initial data for the NCAR general circulation model. The model requires, as initial conditions, that both pressure and horizontal wind fields be prescribed. It is characteristic of any "primitive equation" model (based on the Eulerian hydrodynamic equations modified by the assumption of hydrostatic balance) that the model is very sensitive to the initial fields of wind and pressure. Unless these fields are suitably adjusted to each other, the forecast pattern may contain excessive noise in the form of high-frequency gravity-inertia waves. Meteorologically important motions thereby become obscured. The problem of initial data for the primitive equations has been discussed by Phillips (1960), Washington (1964), and others.

The following procedure is planned: For a given initial distribution of pressure, the stream function field will be computed from a balance equation. The initial divergence field will be computed from the calculated stream function field by using a diagnostic equation which is derived by combining the vorticity equation, the thermodynamic equation, and the continuity equation in such a way as to insure that the time change of vorticity will be initially geostrophic. The velocity potential is then obtained from the divergence field. The initial horizontal velocity components are then obtained from the stream function and the velocity potential.

Simplified Radiation Calculation

The rate of cooling by infrared radiation is specified crudely in the present NCAR general circulation model as a function of temperature, height, and season. A similar parameterization was adopted in the Mintz and Arakawa model. To improve the method of evaluating the cooling rate, Takashi Sasamori developed a machine program (unpublished) to evaluate infrared radiation fluxes by water vapor, carbon dioxide, and ozone in the atmosphere. These constituents are eventually to be incorporated into the general circulation model. The program utilizes the radiation tables compiled by Elsasser and Culbertson (1960), and transfer equations are solved by a numerical quadrature. The program permits inclusion of radiation effects of high, middle, and low level clouds when the cloudiness at each level is given. Similar sophisticated methods have been developed elsewhere for the calculation of radiative flux and heating rate (Manabe and Möller, 1961; Rodgers and Walshaw, 1966). Unfortunately, these methods are computationally unwieldy for use in general circulation experiments. In such experiments cooling rates are computed at frequent time intervals and at each of the numerous grid points. The use of sophisticated radiative models leads to the need for even more computing time for treating radiation than for the dynamic counterpart of the calculation.

Richard Lindzen and Washington are seeking to simplify the method of radiation calculation. Fortunately, in the course of many studies of radiation it has been found that several important simplifications are still moderately accurate. For example, where heating due to water vapor is largest, the "Rosseland mean" is a good approximation of the frequency-dependent absorption coefficient (Yamamoto, 1955); the "Eddington approximation" to the angular distribution of intensity is generally adequate (Goody, 1964); and above 2 km "cooling to space" (discussed by Rodgers and Walshaw, 1966) accounts for much of the radiative cooling. These simplifications have been combined to form a computationally very simple, moderately accurate radiative model with input data which take into account the distributions of temperature, water vapor, and ozone. It is also possible, in the present model, to take into detailed account the clouds in the infrared radiation calculation by merely adding their optical thickness to that of water vapor.

Atmospheric Energy Studies

The diagnostic investigation of large-scale atmospheric energetics has been further pursued by John Brown to aid in evaluation of the results of the general circulation numerical experiments. An insight into the validity of the modeling approximations can in some instances be obtained through direct comparison with atmospheric energy partitioning of the zonal and eddy parts and within the various scales of motion in the eddy flow of the real atmosphere.

However, many difficulties exist in obtaining from actual data reliable estimates of such quantities as zonal and eddy rates of generation of available potential energy, conversion rates of available potential energy into kinetic energy, and frictional dissipation rates. General circulation characteristics are controlled by such energy conversions, and an understanding of such phenomena depends upon a knowledge of atmospheric diabatic heating processes, large-scale vertical motions, and frictional mechanisms. These factors are of course strongly interdependent.

A study aimed at a better understanding of the source of zonal kinetic energy for the abnormal circulation which existed in January 1963 has been completed by Brown (in press). Previous diagnostic calculations made by Wiin-Nielsen, et al. (1964) indicated a depletion by the eddies of zonal kinetic energy in latitudes north of 20°N. However, the zonal kinetic energy showed no signs of decreasing in strength during this month. The energy was evidently supplied through some other mechanism than exchange from eddy to zonal kinetic energy. Brown's study indicates that the terms which had been neglected in the Wiin-Nielsen, et al. calculations were of little importance, with the exception of lateral and vertical boundary terms. It was found that monthly averaged values of these boundary terms were sufficiently large to compensate for exchange of kinetic energy from the zonal flow to the eddies and thus gave a possible explanation for the source of the zonal kinetic energy for the volume of atmosphere under consideration.

Stability of the Westerlies

A numerical investigation of hydrodynamic instability for linearized quasi-geostrophic equations of motions for large-scale atmospheric motions (wavelengths of the order of 10^6 m) is being undertaken by Brown. Characteristics of the baroclinic and barotropic modes of instability are studied separately and in combination by using typical north-south and vertical profiles of the basic wind current and static stability. The numerical technique employed is one of an initial-value approach. This technique, compared with an eigenvalue approach, has the advantage of incorporating a large number of grid points in both vertical and lateral directions in order to minimize truncation errors.

Tests made thus far indicate that the largest amplifying mode for a particular unstable wavelength can be identified with considerable accuracy. Furthermore, results are in good agreement with both the quasi-geostrophic baroclinic and barotropic theories. Tests of the model are being planned to determine conditions sufficient for instability for several basic flow patterns which contain various averaged amounts of zonal available potential energy and available kinetic energy. Preliminary results of a basic westerly flow which contains a jet near 250 mb and an inflection point in the north-south profile indicate the existence of two distinct instability maxima of different wavelength of perturbations (measured in the basic flow direction). The shorter wavelength maximum is characterized by a dominant baroclinic instability effect and a less dominant barotropic damping effect. The longer wavelength instability maximum, on the other hand, is characterized by a dominant barotropic instability and less dominant baroclinic instability effects. We plan to investigate the modifying effects of friction and various diabatic heating forcing functions, incorporated within the linear theory.

Thus, the main purpose of this work is to study:

- Effects of y-dependence (north-south) on baroclinic instability in an adiabatic, frictionless atmosphere (to what extent does the horizontal shear of zonal current modify the linear stability theory?);

- The extent to which frictional dissipation modifies wave growth and structure;

- The extent to which various types of diabatic forcing functions modify the baroclinic-barotropic instability.

Tropical Circulation

Henry van de Boogaard is completing his synoptic study of the transport and conversion of kinetic energy in subtropical latitudes, outlined in the 1965 Annual Report. He also followed up a suggestion that appreciable kinetic energy might be transported through the upper boundary of the Hadley cell. His analysis of computations for a winter day indicated that this transfer amounts to about 50% of the horizontal transport through the northern boundary of the Hadley cell. On the other hand, terms expressing the transfer of energy between the mean and eddy flow and involving the vertical velocity wind component were found to be negligible compared with their horizontal counterparts. A paper reporting on this study is in preparation.

In the Introduction to this LAS report, above, and in the discussion of theoretical prediction of cloud population (p. 57), some reasons are given for our increasing concern with tropical meteorology. In particular, the role of convective transport of heat, moisture, and momentum in the equatorial zone is an important factor in any general circulation model and, by the same token, interactions between convection and synoptic-scale motion in the tropics must be understood in the context of the general circulation.

In recognition of this need, Aylmer Thompson of Texas A & M University and James Sadler of the University of Hawaii collaborated with Zipser and van de Boogaard in collating recommendations of an inter-university and government-agency committee convened in August 1966 for the purpose of designing field experiments in tropical meteorology. As an NCAR working group, they organized conventional and satellite data provided by ESSA and NASA for presentation at the meeting, and subsequently laid out a specific proposal for the first TROMEX (TROpical Meteorology EXperiment) expedition. This expedition will be carried out in the Line Islands (near the equator, south of

Hawaii) in late winter 1967, and will involve the establishment, for a limited period, of several surface and upper-air stations, with use of ground photography, radar and aircraft reconnaissance. The purpose of the Line Islands Experiment is to study characteristics of convective clouds and of synoptic disturbances passing across or near the Islands. During the same period, NASA's synchronous communications satellite, ATS-1, will be stationed over this location. This satellite is equipped with a camera capable of taking high-resolution pictures at frequent intervals. If the satellite continues to be successful, its pictures will be combined with expedition data to provide new information serving to "calibrate" the satellite pictures with more detailed information, and will afford us an opportunity to study for the first time the evolution and movement of tropical synoptic systems over an extended time period. The experiment is designed so that useful new information will be obtained even if the satellite fails.

At a meeting at Goddard Space Flight Center early in January 1966, attended by representatives from ESSA, NASA, NCAR, and the universities, NASA expressed a desire for the development of a research project to evaluate meteorological applications of the IRLS (Interrogation, Recording, and Location System). This system, which will be carried on Nimbus B and D satellites, is capable of tracking balloon-borne transponders. At the meeting, Elmar Reiter of Colorado State University and van de Boogaard were designated to lay out an experiment investigating the summer tropical easterly jet stream over the Indian Ocean area and Africa. A proposal for the Nimbus-D experiment, prepared by Reiter, van de Boogaard, and James Angell of ESSA, has been submitted to NASA. It calls for a preliminary trajectory study at 125 mb over the Indian Ocean and at 25 mb over the equatorial Pacific, to be completed by June 1967. On the basis of the findings of this study, a launch site will be chosen by November 1967.

Last spring NCAR was host to Dr. Kshudi-Ram Saha of the Institute of Tropical Meteorology, Poona, India, who visited as a WMO Fellow. While here, Saha completed a detailed analysis of three-dimensional circulations over southern Asia and neighboring waters, for 7 July 1963, a day well documented by observations of the International Indian Ocean Expedition. Saha's principal finding relates to topographic influences on monsoon circulation: computations indicate marked ascending motions over Arabia, India, and China, and descending motions over the sea areas and over the Himalaya-Tibet region, as would be expected from the distribution of heat and cold sources.

Stratospheric Circulation and Ozone

Meteorological rocket measurements of temperatures in the stratosphere over McMurdo Sound, Antarctica, in mid-winter of 1963, apparently indicated anomalously high temperatures at altitudes above 25 km. These data were originally taken as an indication of an Antarctic stratospheric warming. During the winter of 1963, a radiometer on Tiros VII measured stratospheric temperatures. Paul Julian made a study to compare 15 μ CO_2 absorption-band radiometer data, together with conventional radiosonde data, with rocket-measured temperatures. Radiative source function and equivalent blackbody (EBB) temperature data were compared, assuming the rocket temperature profiles to be correct. A discrepancy of about 10% was noted between observed and assumed EBB temperature data. Comparisons of observed vertical shears (shown by rocket wind data) with those implied by temperature gradients based upon both rocket and radiosonde temperatures, clearly were not compatible. Thus some major question exists as to the reality of the reported southern hemisphere "stratospheric warming." A movement to adopt a uniform definition of the term "stratospheric warming" was a direct outgrowth of this work.

Dr. Roy Berggren, a summer visitor from the Swedish Meteorological and Hydrological Institute, carried out synoptic analyses of the three-dimensional distribution of ozone in the stratosphere and upper troposphere. He used data from the Geophysics Research Directorate-sponsored IQSY ozone network during an interval in which daily ozonesonde observations were taken at North American stations. An objective was to develop a method for representing ozone distribution in greater detail than by mapping using simultaneous observations from the small number of stations. This was accomplished by projecting ozone values from given stations (on preceding and succeeding days) both forward and backward along 24-hr isentropic trajectories, and plotting them on the map for the central time, thus in effect tripling data points for a given day.

Among features revealed by the maps are ozone maxima and minima in a relatively undisturbed westerly current, comparable to those which have been associated traditionally with cyclones and anticyclones. Vertical cross sections also indicate that the double maxima observed on many soundings between the polar front and the subtropical jet stream are associated with extensive ozone-rich layers above the middle-latitude and tropical tropopauses. The distinct ozone minimum between them suggests an incursion northward of ozone-poor air from the high tropical troposphere to the south. Berggren is developing programs by which such analyses can be performed rapidly by computer.

At the request of Dr. Benson Fogle of the Geophysical Institute, University of Alaska, van de Boogaard will participate in a study on noctilucent clouds and their possible effects on atmospheric circulation at 10 and 50 mb. Fogle has furnished the dates of occurrence of noctilucent cloud phenomena, and the relevant series of upper-air synoptic maps will be provided by ESSA.

Southern Hemisphere Meteorology

Results of an investigation dealing with seasonal temperature changes over the southern oceans, discussed in the 1965 Annual Report, have been published by Harry van Loon (1966).

The meridional temperature gradient in the lower troposphere responds to that at the earth's surface, and in middle latitudes it is stronger in summer than in winter due to a greater annual temperature range at 35°S than at 50°S. This is the opposite of what would be expected from seasonal variation of insolation, which is greater at the higher latitude. There is a greater proportion of ocean area in the southern hemisphere than in the northern hemisphere, and computations of the heat budget of the upper oceanic layer demonstrate that the observed behavior can be attributed to combined influences of differences in cloudiness and in vertical stirring above the oceanic thermocline at the two latitudes.

By contrast with middle latitudes, in subantarctic latitudes the temperature gradient and strength of the westerlies show a dominant semiannual variation, with maxima around the spring and autumn equinoxes. Van Loon (in press) found that this effect arises from differences in seasonal cooling and heating trends in middle and high southern latitudes, combined with the circumstance of nearly equal annual temperature ranges, again attributed in great part to the response of the earth's surface to the heat budget. In turn, variation in the temperature gradient is linked to increased cyclonic activity in high oceanic latitudes in the transitional seasons. While the mean pressure in middle latitudes falls with the equatorward shift in the position of the circumpolar trough from autumn to winter, the pressure rises over Australia, South America, and Africa. The resulting increased longitudinal pressure contrast is expressed as an amplification of the mean wave pattern at the surface. The enhanced poleward transfer of warm air accompanying this amplification apparently accounts for the cessation of rapid temperature falls over Antarctica in early winter and for actual mean temperature rises at some stations.

In collaboration with Dr. Aylmer Thompson of Texas A & M University, van Loon has analyzed a series of ten daily sea-level and 500-mb maps of the southern hemisphere with the aid of Tiros VII cloud photographs and radiation measurements. It was evident that the combination of surface and upper air data from comparatively few stations over the southern oceans with the satellite data sufficed to give a reasonable picture of the atmospheric circulation, with more detail than either set of data would have given alone. In addition, van Loon prepared a series of five daily 200-mb southern hemisphere maps for use in a global numerical experiment by the Dynamical Meteorology group.

Dr. J. J. Taljaard, a visitor from the South African Weather Bureau, is collaborating with van Loon on a monograph which will summarize the structure of southern hemisphere circulation at different levels and seasons. Initial work is under way on collection and analysis of data, and on devising suitable methods for vertical extrapolation in the extensive regions of sparse data.

Zonal Index Cycle

An investigation of the zonal index cycle was completed and published by Julian (1966a). This study, outlined in the 1965 Annual Report, disclosed that there is no regular periodicity in fluctuations in strength of the upper-level westerlies.

Atmospheric Tides

Richard Lindzen has been working on solar and lunar atmospheric tides, with special emphasis on daily oscillations of the atmosphere. The most prominent of these are the diurnal and semidiurnal oscillations, which are relatively unimportant in the troposphere, but are almost dominant in the upper atmosphere. The oscillations are mainly excited by the daily variation of solar heating due to absorption by ozone and water vapor. Other detectable oscillations are due to lunar gravitation.

The most evident manifestation of these oscillations prior to recent rocket investigations has been the surface pressure oscillations. These amount to 1 mb for the solar semidiurnal, 0.6 mb for the solar diurnal, and 0.06 mb for the lunar semidiurnal oscillations at the equator where, in general, such oscillations are strongest. However, recent rocket investigations show that above the 40-km level diurnal oscillations in wind and temperature often exceed the semidiurnal oscillations.

The classic theory of such oscillations leads to two sets of equations for each period and wave number: one, in latitude dependence (Laplace's tidal equation), leads to the calculation of a set of functions (Hough modes) and eigenvalues (equivalent depths); the other gives the altitude dependence of each Hough mode as a response to the altitude distribution of the driving functions.

The complete set of Hough functions for the solar diurnal oscillation has only recently been obtained (Lindzen, 1966a; Haurwitz, 1965; Kato, 1966). Applying this discovery Lindzen (in press) has calculated the velocity, temperature, and pressure fields resulting from the diurnal component of solar heating. These fields are characterized by their large magnitude and seemingly irregular structure. The calculations are for an isothermal basic state under adiabatic conditions. Recent observations support the results of these calculations (Reed, et al., 1966; Theon, et al., 1966). Rodgers and Walshaw (1966) found that infrared cooling can be represented in most cases by Newtonian cooling (i.e., the cooling rate is expressed by the function $aT + b$). Moreover, the magnitude of the coefficient a can be enhanced by ozone photochemistry (Lindzen and Goody, 1965).

Newtonian cooling has been incorporated in the general theory of tides (Lindzen and McKenzie, in press), and a numerical program has been developed to calculate tables of oscillatory fields for 1-km intervals of altitude and 5° intervals of latitude for given distributions of Newtonian cooling-rate coefficients, basic temperature, and drive. The program is being used to investigate not only the diurnal oscillation for the earth's atmosphere, but also the diurnal oscillation of the Martian atmosphere (with C. Leovy of The RAND Corporation), and the lunar and solar semidiurnal oscillations of the earth's atmosphere. Attempts are being made to modify the lower boundary condition to take account of boundary stress -- a matter of potential importance for the semidiurnal oscillations.

A number of interesting results have already been obtained. It has been found, for example, that the diurnal fields are unstable at various times of day and for certain latitudes in the neighborhood of 90 km. It thus appears that the diurnal oscillation may be a considerable source of high-frequency disturbances in the form of turbulence and gravity waves. It has also been found that tropospheric lapse rate is a significant factor in determining high-level winds.

Investigations have also been made into the daily oscillations of the thermosphere, where day-night temperature differences may reach 500°C. Lindzen (1966b; also, in press) has found that winds on the order of 200 m/sec can result from these oscillations despite the effects of ion drag and viscosity.

Propagating and Trapped Modes of Planetary Oscillations

During Lindzen's investigation (1966a) of Laplace's tidal equation for the diurnal oscillation, several interesting and suggestive features were uncovered. In particular, Lindzen found that there are two distinct sets of eigenfunction-eigenvalues. One set consists of eigenfunctions whose amplitude is confined primarily to latitudes equatorward from the critical latitudes (where the frequency of the oscillation equals twice the vertical component of the earth's rotation). Associated with these eigenfunctions are small positive equivalent depths, indicating that these modes propagate freely away from drive levels. The other set consists of eigenfunctions whose amplitude is primarily in the region poleward from the critical latitudes. These eigenfunctions corresponding to negative equivalent depths indicate that these modes are trapped (i.e., do not propagate away from drive regions).

Lindzen felt that these properties might be shared by waves of longer periods and other wave numbers which are larger than unity. However, Laplace's tidal equation is too difficult to solve in general. Instead Lindzen sought to use β-planes to simulate the properties of Laplace's equation. He found in the case of diurnal waves that an equatorially centered β-plane satisfactorily produced the propagating modes (Rosenthal, 1965) while a mid-latitude β-plane produced the trapped modes (Thompson, 1961). These β-plane models have been used to investigate waves of arbitrary periods and wave numbers.

Lindzen found that at the equator propagating modes exist for all periods and wave numbers. He found that at midlatitudes, for many important periods, ω, and wave numbers, n, namely $\omega \sim 2\pi/5$ days, $n \sim 5$, the waves are trapped in the vertical. However, for sufficiently long periods waves begin to propagate. Thus, a strong wind may "untrap" a wave by doppler-shifting its frequency downward. The implications of these results for the general circulation in the stratosphere are being investigated.

For a discussion of somewhat related work by Walter Jones on gravity-wave oscillations and their interactions with turbulent motions, see Wave-Turbulence Interaction, p. 65.

Finite-Difference Integration Scheme

In a recent literature survey made by John Gary (1966b) of the NCAR Computing Facility and submitted to the NCAR-IBM Weather Study Committee (Kolsky, 1966), it was concluded that there is no single best finite-difference scheme for the stepwise numerical integration of the general circulation equations. This does not imply, however, that no progress has been made. On the contrary, about five years ago it was simply a dream to be able to integrate meteorological equations for a period of 100 days. Several schemes are now available to realize this dream. Gary's conclusion, therefore, seems to emphasize the necessity for further improvement in finite-difference integration schemes applicable to meteorological problems. We feel that continuous effort should be made on this subject.

Two papers on such research were published in 1966. One is by Houghton, Kasahara, and Washington, who were concerned with computational stability of a long-term (100-day) integration scheme of the barotropic equations. Another paper by David Williamson, a summer visitor from MIT, concerns the stability of many finite-difference schemes for partial differential equations of geophysical fluid dynamics containing advection, inertia, and diffusion terms.

The NCAR general circulation model adopts spherical coordinates and a horizontal grid network having a spacing of 5° in both longitude and latitude. Approaching both poles, the grid is coarsened in the longitudinal direction in order to keep the geographical distances more uniform. Williamson has been working with Kasahara to investigate the influence of coarsening the grid in the longitudinal direction upon the numerical solutions based on a global integration of the barotropic equations in the Eulerian form.

Climatic Change

Paul Julian has carried out statistical studies of tree rings and climate variations, in support of the objective outlined in the 1965 Annual Report, to clarify the interpretation of tree-ring variations as quantitative indicators of climatic changes before the advent of weather records. Cores taken from trees along a transect of the Colorado Front Range have been used to begin construction of a statistical model relating tree-ring index width to monthly means of precipitation and temperature data. The problems attacked initially were:

1) What measurable statistical parameters of the tree-ring index sample characterize the sensitivity of the index data to climatic parameters?

2) What combination of precipitation and temperature data is best related to ring index variability?

3) What time scales of precipitation and temperature variability furnish the most sensitive indices to which tree-ring growth can be related?

Preliminary results for (1) and (2) indicate that the quasi-objectively chosen superior sites, characterized by high ring variability (high standard deviation), low serial correlation, and a high proportion of the total variability of all cores contained in the group variance (from an analysis of variance), are also those sites whose group index correlates most closely with climatic data. Various statistical techniques, all dependent essentially upon the partial correlation matrix, indicate that the ring indices are primarily responding to changes in late-winter and spring precipitation immediately preceding the growing season. Temperature does not, on the basis of the linear techniques utilized to date, seem to be so related in any consistent manner.

Further work is planned on nonlinear combinations of the precipitation and temperature data and upon item (3) above. Ultimately, the statistical model will be used to investigate past climatic change in areas of western United States for which sensitive tree-ring sites are available. The effort has been and will continue to be carried out with the close cooperation of Dr. Harold C. Fritts of the Tree Ring Laboratory of the University of Arizona.

MEDIUM TO SMALL-SCALE MOTIONS

Prediction of Cloud Populations

Clouds are important in the large-scale motion of the atmosphere, and therefore in designing a general circulation model of the atmosphere, for three main reasons:

• The latent heat released during the formation of clouds provides a major heat source for the atmosphere.

• Absorption, reflection, and scattering of short- and long-wave radiation by clouds alter the distribution of heating and cooling in the atmosphere.

• Large amounts of sensible heat, water vapor, and momentum are transported upward by tall cumulus clouds; as a result, these clouds stabilize the stratification of the atmosphere.

The occurrence of stratiform clouds which, for example, are associated with the warm fronts of middle latitude cyclones, can be predicted rather successfully by numerical forecasting methods. The prediction of cumuliform clouds, on the other hand, is notoriously difficult, in part because the scale of cumulus clouds is small -- on the order of a few kilometers -- and in part because the mechanism of their formation is more difficult to model than that of stratiform clouds. The dynamics of isolated cumulus clouds have also been studied. To study the evolution of such clouds, one must use a horizontal mesh size of 100 m or less, as has been done by Lilly (1962), Ogura (1963), and Orville (1965). Since current general circulation models use a mesh size on the order of 300 km, it seems hopeless to try to incorporate the calculations of individual cumulus clouds in such a large-scale forecasting model.

However, the situation is not that difficult, because it is not necessary to predict the motions of individual convective clouds in the large-scale flows. The problems are, then, to predict the population of cumulus clouds, and to investigate the influence of large-scale flow on the formation of organized cumulus clouds. These problems are currently being studied by Kasahara and Tomio Asai (1966).

Let us consider a tall cumulonimbus cloud of a given horizontal cross-section area. To calculate the number of clouds present in a given area (say in a 100-km square), one need not ask how they are distributed in the area. One can picture a given area covered by cloud areas and cloudless areas. Since the size of each cloud is given, one could compute the maximum population of the clouds, if one knew the size of the cloudless area associated with an individual cloud. The problem now reduces to finding the relationship between the ratio of the cloud (updraft) area to the associated cloudless area (area of compensating downward motion) and the large-scale environmental (synoptic) conditions.

To solve this problem, we must select a cumulus cloud model. A number of models have been proposed in the past by many investigators. However, earlier studies of cumulus clouds have been concerned primarily with the physical forms of buoyant elements in the updraft and with the mechanism of entrainment of environmental air into the updraft. In all these studies, the cloud consisted of only a single updraft in an environment at rest, and included no consideration of the effect of compensating downward currents associated with the updraft. From observations of cumulonimbus clouds and of Bénard cell convections, it is evident that the role of compensating currents is important.

Asai and Kasahara (in press) designed a new cumulus cloud model, to use in the prediction of cumulus cloud population. The model consists of two concentric air columns: the inside column corresponds to an updraft region (cloud area) and the outside column corresponds to the surrounding downward motion region (cloudless area). The effects of large-scale synoptic conditions are included through the application of boundary conditions at the outside boundary of the cloudless area. For a given size of cloud and prescribed large-scale environmental conditions, the size of the compensating downward motion is determined by assuming that the cloud transports heat most efficiently in the upward direction.

Asai and Kasahara showed that the ratio between the width of the cumulus towers and that of the cloudless intervals is a few per cent for the most efficient upward heat transport. This suggests that the most active cloud systems appear when the cloud towers occupy only a small portion of a given area. In this study, however, the horizontal diameter of cumulus clouds still remained undetermined. Asai (1966, unpublished) recently extended the work of Asai and Kasahara (in press) to determine a preferred absolute size of cumulus clouds as well as a preferred ratio between the ascending and descending areas.

Thermal Convection

The work described in the preceding section concerns an effort to develop a statistical description of convective clouds in the atmosphere. A closely related set of studies concerns the details of the convective process itself. Some of these are laboratory experiments, and some are attempts to develop numerical or analytical models of a convective cell. In these studies the role of turbulence is generally important, as it relates to the fluctuations of thermal and motion fields. Eventually, the microphysics of cloud particles and the release of latent heat of condensation must be considered in a complete cloud model -- in fact, this is one of the exciting goals of this research on convection.

Laboratory Investigations

NCAR's laboratory convection chamber has been used by James Deardorff and Glen Willis in the past year to study the onset of thermal turbulence. They found that the appearance of regular temperature fluctuations due to convection and their gradual development into turbulence depend strongly upon the Prandtl number of the fluid employed (Willis and Deardorff, in press). A recent theory of L. N. Howard (1963) partly explains the observed dependence for large Prandtl number, but not for fluids such as air.

The discrete heat-flux transitions of Malkus (1954), a different phenomenon, were confirmed experimentally (Willis and Deardorff, in press) for two different fluids. A revised, quasi-linear stability analysis showed that the transitions can be explained only partially, if at all, by instability of successive vertical modes. This conclusion stands in contrast to the original explanation of Malkus and that erroneously reported by Willis and Deardorff.

At the largest Rayleigh number feasibly attained in their convection chamber (8×10^7), Deardorff and Willis searched for a mean temperature profile characteristic of "free convection." C. H. B. Priestley (1959) showed that in such a profile the temperature gradient would vary as the -4/3 power of the height near the surface. No such relationship was found, although there were strong indications that a free-convection regime would have appeared at considerably larger Rayleigh numbers.

At present, while Deardorff is at the University of Washington, Willis is investigating the time-dependent penetrative convection from a warm surface into an overlying stable layer. He hopes to determine the behavior of the surface heat flux with respect to the height and temperature of the inversion base, and to determine how a sharply defined inversion base is maintained by (or in spite of) the underlying turbulence. Initial experiments by Lilly, using salt solutions, indicate that a fraction of the turbulent energy produced by buoyancy is transformed back into potential energy by entrainment of the upper stable layer (as postulated by Ball, 1960). In contrast to Ball's conclusions, however, this fraction appears always to be substantially less than unity and approaches zero as the thermal intensity becomes small compared to the inversion strength.

Layered Penetrative Convection

In various regions of important air mass modification over the sea or large lakes, thermal convection occurs in relatively shallow, non-precipitating layers under a strong inversion and in the presence of large-scale subsidence. A proper description of this type of cloud regime requires consideration of the entrainment of dry air and of radiation losses at the cloud top, as well as the air-surface thermodynamic exchanges. Lilly has developed a system of modeling equations for representation of time-dependent parameters of such a regime as functions of large-scale environmental conditions, i.e., the surface geostrophic wind and temperature and the upper air subsidence rate, temperature, and humidity. The key requirement for closure of the system is specification of the turbulent energy balance of the mixed layer, since this balance determines the entrainment of warm, dry air from above. Preliminary results of laboratory experiments on penetrative convection appear to lead to relations at least partially transferable to the cloud model. Work continues on the model and on determination of solutions characteristic of real conditions and verifiable by field data and/or by more detailed numerical simulation experiments.

Simulation of Turbulent Thermal Convection

At present the numerical simulation of turbulent fluid dynamics is partially stymied by the apparent necessity of three-dimensional calculation models and the inadequacy of the resolution allowed by existing computers. Although Deardorff (1965) has performed calculations with a model in which the third dimension is replaced by an artificial "data sandwich" of three planes, the model has not yet been shown to be an adequate replacement for three dimensions. A partial solution to the resolution problem is offered by a method proposed by Lilly (1966a, unpublished; also, in press) for connecting explicitly calculated motions in the energy-containing scale range to an assumed inertial range at scales near and below the resolution limit of the computer model. Lilly's model appears to be consistent with the existence of the Kolmogoroff spectrum function and with Townsend's laboratory results on suddenly strained turbulence, but it has not been adequately tested in numerical computations. Lilly plans a series of such computations, hopefully concurrent with improving computer capabilities, in which various kinds of laboratory turbulence experiments will be simulated by the computer. The ultimate goal is simulation of cloud elements and ensembles, including their microphysical interactions.

Cumulus Convection, Interactions with Large-Scale Motions, and Severe Storms

In continuation of investigations reported in the 1965 Annual Report, Chester Newton (1966a, 1966b) analyzed circulations in squall-line thunderstorms under the influence of strong vertical shear. In the situation analyzed, the configurations of the radar echoes indicated that updrafts were tilted in a direction opposing the vertical wind shear. Such a structure permits condensed water to fall out of the updraft into dry air, which enters a storm in middle levels and undercuts the updraft air. As a consequence, the vigor of both the updraft and downdraft is enhanced, the updraft because it is relieved of the weight of liquid water which would otherwise oppose the buoyancy due to its warmth, and the downdraft because water evaporated into it causes chilling and sinking of the cold air under the influence of gravity.

Although these general features were known before, the novel aspect of this study is a relatively complete evaluation of the mass flows of air and water in the different branches of the storm circulation. For a single large storm, the air flux was 700 kton/sec in the updraft, and 400 kton/sec in the downdraft. One of the questions that has existed in the study of severe thunderstorms, fundamental to understanding the thermodynamic processes, concerns the degree of mixing of outside air into the updraft. It was found possible to deduce, in an indirect fashion, that although the inner core of an updraft is relatively protected from such mixing (and can thus penetrate into the stratosphere), strong mixing takes place into its outer sheath, in which the air is prevented from rising to the tropopause.

Bernice Ackerman, a summer visitor from the University of Chicago, investigated the feasibility of measuring motions relative to a cloud by tracing the movements of chaff bundles using a vertical-scan radar mounted in an aircraft making repeated passes by the cloud. We hope that this technique will give information on the extent to which air actually enters into or flows around a cloud, when there is a wind relative to it.

Fred Bates, summer visitor from Saint Louis University, carried out research on the dynamics of convective clouds, and also taught in an Aviation Facility program to train students in the use of aircraft for meteorological research. In several flights during the summer, Bates, his students, and Ralph Coleman of NCAR acquired time-lapse photographs and radar data related especially to the "flanking cloud lines," the cumulus congestus which tends to build up on the upwind sides of cumulonimbus clouds when there is strong vertical shear. Tests of a 1.86-cm radar, developed and loaned by Bendix, indicated that short-wavelength radar can usefully detect congestus clouds, probably before they reach the active precipitation stage. Using the Control Data 6600 computer, Bates and his co-workers also developed a model of the three-dimensional structure of the updraft pertaining to a large, severe convective storm imbedded in an environment with vertical shear.

In support of planning by the National Hail Suppression Research Project (NHSRP), Newton collaborated with Harold Orville and Fred Bates to prepare a report on the dynamics of severe storms. The report, which provides background information on the structure and mechanics of convective storms, and suggests the observations needed to clarify them further, will be incorporated in a proposal to be submitted to the National Science Foundation by the Steering Committee of the NHSRP early in 1967.

Convective Motions in the Atmosphere

We have already referred to attempts in NCAR and jointly with other groups to document the behavior of convective clouds, especially in the tropics. A special and most difficult aspect of this work is the observing of meso-scale motions associated with atmospheric convection, both in cumulus clouds and in the clear air under and around them. These motions are at present poorly known, but a knowledge of them is essential in order to test the theories that have been developed. We are developing an airborne system for measuring the moderate motions associated with convection, and a dropsonde system for probing thunderstorms. We intend to supplement both of these with a doppler radar system.

Airborne Air Velocity Measuring Systems

Recent investigations of atmospheric turbulence by airborne instrumentation indicate a requirement, especially in heat flux measurements, for a larger usable frequency range, both at the low frequency and high frequency ends (Lenschow and Johnson, in preparation; Warner and Telford, 1965). Donald Lenschow is developing an airborne air velocity measuring system capable of measuring fluctuations to 10 cm/sec for periods of at least 100 sec and mean wind to 50 cm/sec. Two separate instruments are necessary for a complete system: a stabilized platform for determining the airplane attitude angles and for mounting accelerometers to measure the acceleration of the airplane, and a gust probe for measuring the velocity of the air with respect to the airplane. Lenschow has evaluated various inertially stabilized navigation systems for use on the stabilized platform, but no decision has yet been reached as to which system will be selected. We have bought a fixed-vane gust probe which Lenschow will test in Australia in conjunction with the turbulence measuring system developed by the Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization. The gust probe, and a fast-response thermometer, also to be tested in Australia, will extend the range of measurement of vertical velocity and temperature in the Australian system to wavelengths as short as 2 m. These instruments will reduce uncertainty in determining the contributions of high-frequency components of vertical velocity and temperature to total vertical sensible heat flux.

Dropsonde Air Velocity Measuring System

A dropsonde system is being developed by Robert Bushnell and his group, for measuring the violent air motions in and around thunderstorms, where it is often unsafe to fly aircraft.

The principle is simple: measure the relative air motion past a falling body equipped with a drag chute, and at the same time measure accurately the position of the sonde from the ground. But inside a cumulonimbus cloud, ice builds up heavily on some parts of the dropsonde, so that a great deal of the power in the sonde must be used to heat the pilot-static head that measures relative flow of air.

In the past year, ARF Products, Inc., of Boulder has delivered 30 dropsondes built according to NCAR specifications, and most of these have been tested near New Raymer, Colorado, by dropping them from the NCAR Queen Air at about 28,000 ft. (Eventually such drops will have to be from much higher altitudes in order to study mature thunderstorms.) All of these dropsondes include a terminal safety parachute to assure the safety of people and property on the ground and to reduce landing damage to the sondes. Some sondes were also tested in a vertical wind tunnel, in which ice accretion can be simulated. (Growth on the unheated part of the dropsonde body resembles the bumpy appearance of a large hailstone.)

In the tests five dropsondes produced good records of vertical wind structure; other sondes were equipped for other engineering studies (one of which was the successful incorporation of a camera), and some experienced mechanical or telemetering troubles.

Bushnell is also developing a radar with a high-contrast indicator, an adaptation of the regular M-33, which will show areas of precipitation more clearly. There has been a delay in obtaining for this radar system a special antenna that meets tolerance requirements, but some reasonably satisfactory measurements were obtained during the 1966 summer storm season.

Boundary Layer Problems

Air-Water Interaction

Better understanding of exchange processes between the atmosphere and the solid and liquid surface of the earth may be crucial to improving methods for predicting the behavior of atmospheric motion. Our program of laboratory investigations of turbulent air-water flow is contributing to improved understanding of fundamental aerodynamics involved in this class of problems.

Laboratory investigations by George Hidy, in collaboration with E. J. Plate's group at Colorado State University (CSU), begun in 1963, have continued as planned and have yielded information about several interesting features of boundary layers near an air-water boundary. General properties of air motion over small waves have been determined, and a mechanism of wave growth based on the Benjamin-Miles theory for energy exchange by shearing flow has been verified, at least qualitatively.

Hidy and his collaborators are currently studying several features of the turbulent air motion over small wind waves. They have found, for example, that turbulent air flowing from a smooth solid surface onto growing water waves with phase velocities much less than the wind velocity, reacts to the change in surface roughness in much the same way that is predicted for response to changes in roughness on a solid surface. Modifications in mean flow of the air near the boundary can be interpreted with ideas available from existing boundary layer theory, especially those published recently by A. A. Townsend (1965). Comparisons between experiment and theory and other observations have been made by Plate and Hidy (in press).

The details of the structure of turbulence in the shearing flow of air over water waves are now being investigated in the CSU tunnel by Dale Hess, a graduate student from the University of Washington. Comparison between our results and those reported by other workers for solid boundaries suggests that certain key differences may exist between the two flow fields. We have detected no marked differences in the profiles and spectra of the downstream velocity variance, $\overline{u'^2}$, between flow over a solid boundary and over small wind waves. However, the preliminary analysis of profiles of the variance of vertical velocity, $\overline{w'^2}$, and the Reynolds stress, $\overline{u'w'}$, over growing waves seems to deviate from known solid boundary distributions by significant amounts, especially near the surface.

The growth of small water waves by wind action is being explored further, particularly in reference to the combined Phillips-Miles mechanism discussed by Hidy and Plate (1966). The work of Po Chang and Charles Liu, graduate students at CSU, has indicated, for example, that though the shearing flow of air is responsible for the growth of waves by wind action, the initial, microscopic disturbances on the water are induced by vibration of the tunnel rather than by turbulent oscillations of pressure in the air flow.

The interesting experimental observation that waves grow at different rates depending on whether the net flow of water opposes the air flow or coincides with the direction of the air flow, is being examined theoretically by Ronald Drake, a CSU graduate student. Wondering whether differences in shear in the water near the boundary may be responsible for the differences in growth, Drake is investigating this phenomenon in the light of shearing flow instabilities predicted by a form of the Orr-Summerfeld equation.

Hidy plans to proceed with collaborative studies of air-water boundary flows in the CSU facility. Studies of air turbulence and wave growth will continue to be sustained by NCAR (and by an independent grant to CSU from NSF) for more complete verification of our preliminary results.

Transport of Water Vapor in Shearing Flows

One of the important parameters that should be measured in air flowing over water is the turbulent flux of water vapor. No instruments for making such observations are currently available with speed and sensitivity comparable to the hot wire anemometer. However, it has proven possible to construct an aluminum oxide film sensor for humidity measurements in a cylindrical configuration that is small enough in size and fast enough in response to allow us to undertake this kind of study. Preliminary experiments by Juey-Rong Lai, a graduate assistant from the University of Colorado (now at CSU) who is working with Hidy, indicate that this device may be suitable for such observations. After further preliminary experiments on the operating characteristics of the film sensor, Lai will study the diffusion of heat and water vapor in a round jet. Comparisons between the behavior of heat and mass transfer in this type of shearing flow should give a good indication of the performance of the film sensor. If this device works under known conditions, it will be used to study evaporation in the CSU wind-water tunnel.

Small-Scale Turbulence

Deardorff studied turbulent flow in a channel or wind tunnel by numerical integration of the three-dimensional equations of motion on the Control Data 6600 computer. In this approach, the only important assumptions concern the evaluation of small-scale (sub-grid scale) Reynolds stresses, which were simulated by using a formulation of Lilly (unpublished). The two coefficients associated with these assumptions were varied until best agreement was obtained with experimental results of J. Laufer (1955), for which the highest Reynolds number studied was 123,000. Calculated wind profiles and turbulence intensities were in good agreement, except for the longitudinal intensity, which was calculated too large by a factor of about two.

In an earlier three-dimensional model by Deardorff (unpublished) in which the Reynolds stresses were handled differently, the results of a similar study were quite different. Present attempts to simulate the small-scale Reynolds stresses are too crude to allow us to predict physical quantities, without empirical adjustments of parameters to fit the observations. Possibly, the additional numerical calculation of the time-dependent, small-scale Reynolds stresses, obtained by use of Lilly's complete second-order formulation, would alleviate this pessimistic conclusion.

Mountain Waves and Winds

Areas along the eastern slope of the Rocky Mountains are struck from time to time during winter and spring by strong and occasionally damaging "chinook" winds which suddenly flow down from the mountains. This phenomenon is the North American counterpart of the European foehn. Very few synoptic investigations have been made of weather conditions at the time of typical chinook events, and therefore the cause of the chinook along the Rockies is still not well known. Similar winds observed in the Owens Valley on the east side of the Sierra Nevadas were investigated by the University of California at Los Angeles and the Geophysics Research Directorate of the U. S. Air Force (Holmboe and Klieforth, 1957).

An observational program has been under way for about a year, directed by Douglas Lilly, to define similarities between the Rocky Mountain and Sierra Nevada foehn-type winds, and to determine their relationship to observed and predicted lee disturbances. The program uses ten recording anemometers, six of them along an approximate normal to the crest of the Front Range, just west of Boulder. Arrangements have been made with the Facilities Laboratory for launching and radar tracking of small transponder-equipped constant-volume balloons, which will follow air trajectories over and close to the mountain and high plains topography. A number of airplane flights, using an NCAR Queen Air equipped for measuring horizontal wind vectors (by doppler navigator), temperature, pressure, and humidity will be made at levels within the troposphere but somewhat above the balloon trajectories. Because of various operational difficulties, few usable data were obtained in the winter of 1965-66, but some success has already been achieved in the winter of 1966-67.

Literature on air flow over mountains extends from purely theoretical studies on mountain waves to case studies of synoptic weather conditions at the time of strong winds (e.g., Alaka, 1960). The theoretical studies are mostly based upon linear perturbation methods; very little work has been done from a nonlinear aspect. One of the drawbacks of using linearized theories is that we miss the phenomenon of "hydraulic jump," which can arise only from nonlinear interactions. Kuettner (1959), for example, attempted to apply the concept of jump in hydraulics to explain the appearance of rotor clouds in the lee of mountains.

Houghton and Kasahara (in press) are making a theoretical investigation of the nature of hydraulic jumps in flows over a ridge, based upon the one-dimensional time-dependent "shallow water" equations which govern the motions of an incompressible, homogeneous, inviscid, hydrostatic fluid. Their model gives a crude representation of atmospheric flow, but it corresponds very closely to laboratory experiments conducted by Long (1954) at Johns Hopkins University. Critical conditions are derived for formation of hydraulic jumps on both the windward and leeward sides of a ridge. Special emphasis is put on determining analytically the structure of flows with jumps. Time-dependent solutions are obtained numerically to demonstrate the evolution of the various features of flow. The dd80 data display unit at the output of the computer is used to make movies demonstrating the results.

Since the present model is essentially a single layer, it does not permit a study of the vertical extent of hydraulic jumps associated with a ridge. For this reason, Houghton, Kasahara, and Eugene Isaacson (Courant Institute, New York University) are extending the present study to that of a two-layer model. By assigning different values to the densities and the flow velocities of the upper and lower fluids, it is possible to investigate the effects of thermal stratification and wind shear upon the formation and structure of hydraulic jumps.

Stability of Frontal Motions

Since about 1920, when workers of the Norwegian School first established a clear connection between fronts and cyclone-scale circulation systems, the concept of fronts has played an essential role in synoptic analysis and forecasting. However, the precise role of fronts in physical interactions of atmospheric circulation systems is not clear. That they are a general characteristic of rotating fluid systems is attested by the fact that they occur not only in the natural atmosphere and oceans, but also in rotating "dishpans" (Fultz, 1952; Faller, 1956), and that they develop to some extent in numerical experiments (Phillips, 1956; Edelman, 1963). Yet the questions of how distinct fronts appear and how they are maintained against friction and dissipation have never been clearly explained (Eliassen, 1962).

One problem is the stability of perturbation motions on the fronts. In the undisturbed state the frontal system consists of two barotropic layers of air separated by a sloping interface (frontal surface) oriented zonally. Each layer is assumed to move eastward with a constant speed of different magnitude, the warmer southern layer (in the northern hemisphere) moving at a greater speed. Solberg (1928) found that, for large-scale motions, perturbations with wavelengths in the range from about 1000 to 3000 km amplify. Physical formulation of the theory was made more realistic later by Kotschin (1932) and recently by Eliasen (1960). In connection with the recent numerical study of frontal motions by Kasahara, Isaacson, and Stoker (1965), an interest arose in comparing the nonlinear solutions to the linear solutions.

D. B. Rao, a postdoctoral fellow in the Advanced Study Program, who has worked on gravitational oscillations in rotating basins (Rao, 1966), is now collaborating with Kasahara on a stability problem similar to that treated by Eliasen. Rao and Kasahara are using a direct numerical approach to find eigenvalues of the two-point boundary value problem with a finite-difference method. Preliminary results of the numerical method agree favorably with analytical results obtained by Eliasen. Since the analytical approach is rather tedious, Eliasen investigated only a few cases. It is hoped that many different cases can be studied by the numerical method. Special emphasis will be placed on investigating (1) the mechanism of the frontal instability (called the Solberg-Hőiland instability), and (2) a relationship between the frontal instability and the long wave instability (Charney-Eady instability).

Kasahara and Rao are also working on stability of a two-layer fluid system contained in a rotating circular basin, a problem which was treated observationally by Fultz (1952) and theoretically, in part, by Lowell (1958).

Wave-Turbulence Interaction

Walter Jones is studying the generation and propagation of sound and gravity waves in fluid media. Specifically, he is studying generation of gravity waves by turbulence, propagation of waves in atmospheres with mean shear flows, and processes by which waves interact nonlinearly to produce or alter mean atmospheric flows.

More than a decade ago Lighthill (1952) developed a theory for the generation of sound by turbulence, calculating the amount of acoustic energy radiated from a given volume from pertinent statistical characteristics of turbulence. Proudman (1952) added to the value of this theory by relating, approximately, the required statistical characteristics to gross measures of turbulent intensity.

The Lighthill theory was developed for a homogeneous fluid. It is not applicable when the effects of gravity are important, i.e., for long waves and low frequencies. Jones is attempting to extend the theory to cover such cases. We hope that two important questions can ultimately be answered: (1) Can turbulence generate waves which may propagate to and be important in other regions of the atmosphere? (2) Can the energy loss through wave generation bring about important modifications of turbulence spectra?

Jones has concentrated on specification of wave energy radiation for prescribed statistical characteristics of turbulence, formulating the problem in terms of frequencies and horizontal wave numbers as independent variables. Results show that if turbulent forcing is reasonably broad-banded in frequency and wave number, certain scales and frequencies of waves are excited with relatively high efficiency. One particularly efficiently generated wave corresponds quite closely to the 300-sec oscillations found in the solar atmosphere, and to the periods of radio doppler-shift oscillations observed in reflections from the ionosphere by Kenneth Davies of ITSA.

The second portion of the problem, specifying the relevant statistical parameters in terms of some gross measure of turbulence, must be regarded as a very difficult task. Some hope is held that useful analogies may be drawn between generation and absorption of gravity-acoustic waves by turbulence, and processes of radiative transfer.

If internal gravity waves apparently observed at and above the mesopause have their origin in the troposphere, they must be able to propagate through the intervening levels. Their propagation characteristics are influenced by the temperature and especially by the wind structure of the atmosphere. The governing wave equations have mathematical singularities if the horizontal trace velocity of the wave equals the corresponding component of mean fluid velocity. (The singularity is that involved in the instability of a stratified fluid with shear flow, the Kelvin-Helmholtz instability.)

It has been difficult to determine whether an internal gravity wave is transmitted through such a singular level (see also discussion of atmospheric tides, p. 55). Somewhat conflicting studies by Hines and Reddy and by Booker and Bretherton are currently in press. During the summer of 1966, William Taffe, a student from the University of Chicago, worked with Jones on numerical extensions of the Booker-Bretherton analysis (Jones and Taffe, in preparation).

Jones is extending the study to the case of a rotating atmosphere. At present it appears that rotation produces important modifications in wave propagation at a singular level, even when wave frequency is high compared with the rotational frequency. He also hopes to generalize the theory of mass, momentum, and energy transport by waves in fluids with arbitrary flow, especially in the light of points made by Hines and Reddy. These transport properties involve nonlinear self-interactions of waves. Jones has proposed that they may be the source of supergranulations in the solar chromosphere and may also be a means for tide-induced mean circulations in the lower thermosphere.

Synoptic Aerology

Chester Newton has continued to collaborate with Erik Palmén of the Academy of Finland in preparation of a book treating the structures of atmospheric disturbances and their relations to the general circulation. This work is approaching completion.

Satellite Workshop

The Proceedings of the Satellite Workshop held at NCAR in August 1965 have been edited by van de Boogaard. They will appear in early 1967 as NCAR Technical Note 11 and will contain all papers presented at the meeting, with comments by the participants.

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ATMOSPHERIC MICROPHYSICS AND CHEMISTRY

The atmosphere is obviously not a homogeneous mixture of gases. If it were, the task of the atmospheric scientist would be infinitely simpler. Variations in water vapor and clouds of water droplets and aerosols of many sorts that float in the atmosphere have a major effect on the heat budget of an air mass, and "the weather" as we think of it is determined in large part by the presence or absence of fog, rain, snow, hail, lightning, smog, blowing dust, etc. In the sections that follow we will describe some of the studies in LAS that deal with these variations in composition of the atmosphere, their physical effects, and some of the methods that have been developed for measuring them.

Two major applied-research problems confront environmental scientists in the area of microphysics and chemistry: (1) air pollution or air conservation, and (2) weather modification, or, more specifically, precipitation modification. Several of the programs in LAS bear rather directly on these problems.

The purpose of these LAS programs is to lay the groundwork of understanding that is needed for real advancement -- to "do our homework," as it were.

In describing these programs it will be convenient to separate microphysics and chemistry to some extent, even though they tend to be so interrelated that this is a dangerous thing to do. We will deal first with the natural and artificial aerosols that float in the air, including cloud particles -- the studies of the latter being directly related to the important question of why precipitation occurs. Related to this question are our studies of the physics of crystal growth and nucleation in bulk water. We will then deal with trace gases in the atmosphere, both natural and man-made, and their chemical and photochemical reactions. Last, but not least, we will deal with two powerful optical techniques that are being developed in LAS to probe the atmosphere for trace gases and aerosols.

AEROSOLS, PRECIPITATION PROCESSES, AND ATMOSPHERIC ELECTRICITY

Dry Aerosols

Dynamics of Aerocolloidal Systems and Coagulation

Until shortly after World War II the dynamics of aerosols (or aerocolloids, and for the moment we will exclude cloud droplets) developed rather slowly. Because of new interests in microscopic particles suspended in the atmosphere, and industrial applications of aerosols, investigation of a variety of problems in aerosol dynamics has taken a more rapid pace in recent years. George Hidy has been working closely with James Brock of the University of Texas to bring many aspects of aerosol theory together into a relatively uniform and consistent structure. Their efforts are providing a framework for a forthcoming monograph on the dynamics of aerocollodial systems.

Hidy and Brock have investigated the role of photophoresis (a force on an aerosol particle due to radiation from one direction causing a difference of temperature across the particle) in increasing the settling rate of spherical particles descending into an idealized stagnant stratosphere (in press). They concluded on theoretical grounds that the photophoretic force would be too small to significantly influence the descent time of particles less than 1μ in radius in the upper atmosphere, and that larger particles are essentially unaffected.

Work is continuing on studies of aerosol coagulation in the 500-liter cylindrical chamber. Paul Brown has undertaken some preliminary studies of coagulation of $1.3\ \mu$-radius polystyrene spheres in the chamber. Although the instrumentation in the chamber is rather crude at this stage, the first results, taken over a period of 110 hr, indicate that the combined effect of rotation of the chamber and electrostatic charging of the aerosol particles may increase the coagulation rate by 10 to 30 times over that predicted by the theory based on brownian motion. To continue experiments to verify features of the theory of aerosol coagulation, Brown has built better devices for generating monodisperse aerosols and for controlling the charge on the aerosols. Furthermore, it has become necessary to begin designing new instrumentation for measuring particle concentrations and their size distributions. This effort has started with the help of suggestions from Alexander Goetz and Othmar Preining, the latter at the University of Vienna, and with the help of Kenneth Whitby's group at the University of Minnesota.

Theoretical work is continuing on the effect of different size distributions in coagulating aerosols. The numerical integration scheme of E. X. Berry (University of Nevada) has been programmed on the NCAR computer. Several discussions on the theory of self-preserving size spectra (e.g., that of Friedlander and Wang, in press) were held during the summer in connection with the visit to NCAR of S. K. Friedlander (California Institute of Technology). This theory appears potentially useful in studying the behavior of all coagulating (coalescing) disperse systems, regardless of the mechanism for collision of particles.

Collection and Analysis

In an effort to characterize the continental tropospheric aerosol population, Irving Blifford has made approximately twenty aircraft impactor collections at Scottsbluff, Nebraska, at several altitudes up to 10 km, using filter samplers described below. Most of these single-stage impactor collections have now been measured for particle size and number distribution, and some preliminary results were presented at the September 1966 AGU meeting in Los Angeles. A paper in preparation will describe the entire year's results. Several interesting phenomena have been observed, including maxima in the distribution of particles below 1.0μ in diameter and seasonal variations in the size spectra. Additional aerosol profiles are being collected once per month over Death Valley and over the Pacific Ocean about 150 miles west of Santa Barbara, California. Analysis of these collections is continuing.

A larger, two-stage impactor has been designed and is being flown with the smaller unit. This device collects a large volume of air for analysis of the elemental aerosol composition by x-ray spectrographic techniques. Only a few preliminary results are available; they indicate that it will be possible to determine the aerosol chemical composition, at least for most elements lighter than iron, in three size ranges,

$$< 0.1\mu \; ; \geq 0.1 \text{ to } < 1.0\mu \; ; \text{ and } > 1.0\mu .$$

Every effort is being made to reduce incidental contamination, and to this end all analyses are carried out in a clean area in the new building. Incoming air is filtered and critical processes are conducted in laminar air flow benches. Special techniques are used to clean and purify water, reagents and collecting surfaces.

An air filter system was installed by Julian Shedlovsky on one of the NCAR Queen Air aircraft to sample aerosols up to ~30,000 ft. Sampling rates of 10 to 15 m^3/min ambient air are obtained through specially made polystyrene filters of ~1100 cm^2 area. A series of vertical profiles have been flown in the vicinity of Scottsbluff, Nebraska, since February 1966, along with the impactor sampler described above. Aerosol collections were obtained at 6,000 to 7,500, 10,000, 15,000, 20,000, 25,000, and 30,000 ft. These samples are being analzed for radioactivity and chemical composition. The gamma-ray spectrum of exposed filters has been measured and the activities due to Be^7 and Cs^{137} determined. The results to date of these measurements are summarized as follows:

- In each profile the Be^7/Cs^{137} ratio has remained constant within ~20%, indicating little change from day to day in the exchange with the stratosphere at a given tropospheric level.

• The relative amounts of activity collected on the filters in a profile appear to be in qualitative agreement with the total number of particles collected by impaction at each level.

• On several occasions the radioactive concentrations showed very steep gradients at the upper levels, with as much as two orders of magnitude greater concentration between the 30,000- and 25,000-ft levels. Such differences were observed only at times of low tropopauses, indicating that stratospheric air was being sampled at the upper level.

In addition to radioactive measurements, the samples are currently being analyzed for their chemical composition by a combination of neutron activation, x-ray fluorescence, and x-ray diffraction techniques. For the few samples analyzed so far, results indicate that at all levels the majority of the collected aerosols consist of terrestrial dirt: a mixture of silicates, quartz, micas, and clays. One surprising feature is that there are a large number of particles in the 10 to 100 μ range at 15,000 ft. At higher levels the number of such particles is very small. A few measurements of the sulfur content of the samples indicate that the sulfur mixing ratio may increase from 20,000 to 40,000 ft.

These flights will be continued at Scottsbluff until February 1967. Samples are also currently being taken on a monthly basis over the eastern Pacific, and similar radioactivity and chemical composition profiles are being made.

In addition, a series of high altitude RB-57F aircraft filter collections were made last August at 38°N over the United States, with the cooperation of the U. S. Air Weather Service. Samples were collected on clean polystyrene filters (prepared at NCAR) at 36,000, 44,000, 52,000, 60,000 and above 60,000 ft. At the same time, samples were collected with the NCAR aircraft at 10,000, 20,000 and 30,000 ft. These vertical profiles of samples will be used to measure the particulate mixing ratio of a number of elements, including Na, Si, S, and Fe. The concentration of material of meteoritic composition will be measured to estimate the influx rate of extraterrestrial material. Sulfur measurements may aid in resolving the mechanism of formation of the large-particle sulfate layer in the lower stratosphere.

Some persistent difficulties have developed with the method previously in use by James Lodge and his group for detecting trace calcium in aerosols. Evelyn Frank has been working on the problem, and apparently has a solution for the difficulty. If the ultimate technique modifications are significant, a brief note will be published on the subject. The electron microscope techniques used by the atmospheric chemistry section for aerosol studies will be summarized in a report in preparation. A brief note has been published on a visualization of the structure of millipore filters (Frank, Fischer, and Lodge, 1966).

In September 1966, we were joined by Dr. Kvetoslav Spurny, a visitor from the Aerosol Institute of the Czechoslovak Academy of Sciences in Prague. Spurny will test some of his theories on filter efficiency by a series of carefully controlled tests with known aerosol samples.

Scavenging by Precipitation

Many questions center on the efficiency with which raindrops scavenge airborne particles. A series of experiments was completed under the direction of Jan Rosinski, whose object was to determine details of particle trajectories in the 1 to 50 μ diameter range before capture by a spherical object, under conditions corresponding to free-falling raindrops of 0.5 to 3.0 mm diameter. Particle capture by a sphere in the Reynolds number range 137 to 860 was covered. Results will be used to design experiments with liquid water drops.

Related studies involve determination of foreign-particle concentration and size distribution in different forms of precipitation, by analysis of snow and rain samples. In some of the snow samples it was found that there were no particles 13 to 100 μ in diameter. In an analysis of hail from different storms, Rosinski showed that there is a radial increase of foreign particle concentration. His findings may contribute to the solution of such problems as time of growth of a hailstone, altitude at which different layers of a hailstone are formed, and trajectory patterns of hailstones. We can already deduce from the analyses something about the environmental conditions under which a given hailstone was formed.

Hailstones were melted for some of the studies above, and for others they were sliced (using the hot wire technique). Distribution patterns of solid particles in hailstones revealed that some of the hailstones were oriented in the atmosphere during their growth. Further, when hailstone analyses are considered with the results of analysis of rain water collected during hailstorms, we have good reason to think that in mixed clouds, that is, in the presence of both a liquid and ice phase, the "Stephan flow" due to gradients of vapor pressure is a predominant mechanism of capture of micron-size aerosol particles (Rosinski, 1966).

Freezing and/or Condensation Nuclei

A certain class of aerosols -- condensation and freezing nuclei -- plays a crucial role in the formation of clouds and precipitation. Water vapor in the atmosphere always condenses or freezes on microscopic particles. These particles are ubiquitous, but their actual concentrations may vary from place to place by orders of magnitude. Variations in concentration of condensation nuclei have a major effect on the number of cloud or fog droplets that form, and on their size distribution. Furthermore, formation of rain or snow from supercooled clouds depends on the abundance of freezing nuclei -- this is the effect exploited by those who try to modify precipitation by seeding with silver iodide particles, since these are effective freezing nuclei. The LAS program includes studies of freezing nuclei to find out where they come from in the natural environment, what they consist of, and what role they play in the physics of clouds and precipitation. We are, of course, also following closely (and sometimes participating in) efforts elsewhere to modify clouds by seeding them.

Freezing Nuclei from the Upper Atmosphere

The interesting hypothesis was advanced several years ago, by E. G. Bowen of Australia, that meteoritic debris could act as freezing nuclei, and that there might therefore be a correlation between meteoritic activity and rainfall. Although the apparent correlations that he found now have an alternative explanation that does not depend on meteoritic activity, there is nevertheless evidence that the stratosphere is a source of freezing nuclei at certain times, and this matter deserves some further investigation. In particular, the intrusion of stratospheric air into the upper troposphere near the jet stream could bring with it anomalous concentrations of such particles, and these would eventually be drawn into clouds.

One of the programs under the direction of Rosinski consisted of the sampling of ice nuclei at different altitudes and different positions relative to the jet stream core. Samples were collected over a period of one year. The sampling was performed on "Bowen rainfall anomaly" days and at dates between those periods. Data are being analyzed; at present, it looks as if there were an influx of ice nuclei which could be associated with the action of a jet stream. These ice nuclei were found to be stable for hours or maybe days in the atmosphere. Although high concentrations of ice nuclei were not found on all of "Bowen's days," very systematic repetition of some of the periods of high freezing nucleus concentrations has occurred over the past four years.

Another field test program was conducted by Rosinski and his colleagues near Bemidji, Minnesota. A number of sampling flights were conducted between 1 July and 5 August. Filter samples were taken for subsequent analysis of freezing nucleus populations aloft, at altitudes up to 10 km MSL. Daily vertical soundings in the Bemidji area involved samples of about 300 liters of ambient air at altitudes above 5 km MSL. (The ice nucleus counter developed by Gerhard Langer was used below this altitude.) The remainder of the flights included sampling in the vicinity of cumuli and over long distances, sometimes into Canada. Evaluation and analysis of the data from the freezing nucleus counts derived from the samples has been started (Rosinski, in preparation).

Emphasis in these programs is on finding physical correlation between ice nucleus concentration and rainfall, as opposed to the statistical analyses performed by Bigg and others. (The question of the origin of "pools" or clouds of ice nuclei in the troposphere is not considered in this analysis; such pools were located in the atmosphere and their existence cannot be in doubt.) Ice nucleus concentration should have an effect on the amount of rainfall (or snowfall) in the area where moisture-bearing air is mixed with air containing ice nucleus clouds. On a number of occasions when high concentrations of ice nuclei were recorded in Colorado, extremely heavy snowfall appeared subsequently in the central part of the United States. Available data indicate that high ice nucleus concentrations associated with the jet stream may be present over very large areas. Therefore, measurements made in Colorado or in adjacent states under clear-sky conditions may be useful in the future for helping to predict unusually high precipitation along jet streams.

Distribution of Ice Nuclei

The methods of ice nucleus detection developed mainly by Bigg are not always reliable. Several papers, in addition to our work, have indicated deficiencies in present analytical methods of detection. The greatest drawback of all methods, however, is that they do not give continuous determination of ice nucleus concentration.

We have designed and built an ice nucleus detector that can continuously determine ice nucleus concentration at any desired temperature. It can also determine the activation temperature spectrum of ice nuclei. Ice crystals are grown on ice nuclei and then counted with an acoustic particle counter. We have tested the counter extensively with natural ice nuclei and also with silver iodide clouds, and have been able to follow a silver iodide plume on the ground and in the air. This instrument, therefore, can be used in diffusion studies to track a silver iodide cloud and to determine its concentration instantaneously.

The ice nucleus detector is also equipped with an ice crystal separator. This enables us to look at the ice nuclei, providing we can identify them inside an ice crystal. We are now developing an improved separator.

Our progress in detection of ice nuclei has allowed us to start organizing a world-wide ground network for assessment of ice nuclei. Ideally, ice nucleus ground stations should be located carefully to exclude the heavy contamination which is usually produced by urban districts. The first permanent stations are in Kenya (near Nairobi), Italy (Monte Cimone, Sestola), and Germany (Zugspitze, Bavaria); these locations were selected because other meteorological measurements are being taken at each site.

Nucleation Effects by Various Compounds

In a continuing attempt to learn how nucleation occurs naturally in the atmosphere, and how to affect it artificially, chemists have been studying how various compounds -- liquid, solid, and gaseous -- act to provide freezing nuclei. Silver iodide is the most common artificial agent, but other materials are coming to light. An important part of such investigations is the search for more clues as to <u>why</u> some agents are more effective than others.

Continued literature search failed to turn up reports of a simple relationship between the ice-nucleating effect of amino acids and their thermodynamic properties. Accordingly, Farn Parungo's work along this line, which constitutes the most complete existing tabulation of the ice-nucleation effect of amino acids, will be published without a complete interpretation (Parungo and Lodge, in press).

Parungo has also been studying the effect of dissolved inert gases on the spontaneous freezing of small water drops on a cold stage. She has studied the noble gases, the light hydrocarbon gases, and a few miscellaneous species such as air, hydrogen, etc. She has found a substantial effect, generally in the direction indicated by consideration of the structures of the gas hydrates. Her paper on this work is nearly ready for publication. She was assisted in this work by Janet Wood.

Precipitation Processes and Atmospheric Electricity

The reader will by now be aware that a great deal of the LAS work already described deals in one way or another with precipitation -- the dynamics of cumulus clouds, the distributions of condensation and freezing nuclei, the scavenging of particulates by hailstones, etc., are all important aspects of the subject. However, we have reserved for this section those aspects that deal with the growth of cloud droplets to produce rain, snow, or hail. This is, in a sense, the heart of the question that we have alluded to before: Why does it rain?

The main thrusts of this particular work deal with the theory of coalescence and growth of cloud droplets, collision efficiencies of large drops vis-à-vis smaller droplets, the effects of electric charges and electric fields in a cloud on these collisions, the causes of electrification, and the role of the ice phase in a cloud. The last, of course, also bears on the question of hail formation in severe storms, and on possible ways of suppressing hail.

Droplet Growth and Effects of Electrification

As in previous years, the emphasis of the research program under Doyne Sartor has been on the growth of precipitation from convective clouds, including interacting roles of electrification processes and particle growth by accretion and coalescence. All scales of physical processes are intimately interrelated in this subject; we need to know how and to what degree. Microphysical and convective processes involve larger-scale motion and electrical behavior of the atmosphere, the large-scale motion of the atmosphere provides the favorable environment in which convective clouds can mature, and the world-wide atmospheric electric fields are understood to be the result of ionization by cosmic radiation and by the total thunderstorm activity throughout the troposphere. A practical implication (well known to all forecasters) is that few, if any, meaningful quantitative calculations can be made of the sensible weather from clouds, given only the larger-scale circulation. Even less is known about the quantitative relationships between the large-scale atmospheric electric field and thunderstorm activity.

The great range of scales that must be considered in the study of clouds and precipitation is one of the major handicaps in the rapid acquisition of information. It is possible to neglect, but not ignore, inertial forces in the study of the smallest cloud drop motions. The opposite is true of the larger scales of motion that provide favorable or unfavorable environments for cloud formation and development, and of scales of motion that influence the electrical capacitor of the entire atmosphere, continuously recharged by the interaction of vast numbers of cloud particles, and the processes that draw off their charge by leakage currents or electrical breakdown. In this research program, a deliberate effort is made to keep in mind these different scales while concentrating on the more tractable problems of the microphysics of cloud and precipitation growth.

William Atkinson's recent laboratory studies have demonstrated the transfer of charge between freely falling drops, some of the encounters resulting in coalescence and some in near or grazing collision. Atkinson's results place renewed emphasis on the role of particle interaction between charged and uncharged particles in electric fields in separating and redistributing charge in clouds. The generalized induction charging mechanism proposed by Sartor (1954) has been made quantitative by introducing the amount of charge transferred between colliding particles, by the use of present knowledge of particle separation following collision, and by incorporating the change of conductivity and point discharge current as a function of the growing electric field. Results agree with known electric field growth characteristics as a function of time, and provide charging rates that are in excess of the most potent freezing or thermal gradient mechanisms that have been proposed. They also show that, as long as all the cloud particles remain liquid in a thunderstorm, the electric field growth can be expected to be two orders of magnitude less than when the particles are frozen. The calculations point up the need for better quantitative information on the collision, separation, accretion, and coalescence of cloud and precipitation particles, particularly when these particles are charged and in an electrical field environment.

The studies of charge transfer between interacting particles by Atkinson and Ilga Paluch (1966) are very much to this point. Drops having radii as small as 80 μ have been produced, and they are found to discharge through a spark-like process when sufficiently highly charged and sufficiently close together. The discharge process has been observed to occur in less than 1 nsec, which would place the highest frequency of the radio emission from these discharges in the microwave region. It has been possible to distinguish several modes of discharge. When charge on the drops is low, no spark occurs, but the charge transferred is a function of the size of the drop. Higher charges transfer as a spark, the characteristics of which depend on the type of collision (direct or off-center). A second type of discharge has been observed, evidently triggered by the discharges between close drops, but appearing between much more widely separated drops.

Atkinson and Sartor (1966) used laboratory data on dipole moment change and the observed number of drops with charge exceeding that required for discharge, and obtained from this mechanism alone an effective radiation temperature in thunderstorms of about 10^{o}K. This temperature increase should be detectable at microwave frequencies where true thermal radiation from a cloud is low and where cosmic noise has an effective temperature of a few degrees. Detection and identification of a 10^{o}K increment in real clouds would support the validity of observations of charges on thunderstorm particles and droplet concentration. This incremental temperature could be increased by interaction of charged drops in electric fields and by increase in the relative velocity of interacting particles, and/or their collision efficiency -- factors which were not taken into account in the published calculations.

Considerable theoretical effort is being devoted to determining collision efficiencies and relative velocities for the purpose of obtaining collision rates to apply to problems of radio emission and of general cloud physics precipitation growth. Preliminary results of these calculations are very interesting, but application to the atmosphere is still in the future. However, we have found that when we include the electrostatic forces between raindrops in calculations of their collision efficiencies, we obtain infinite values for the collision efficiencies of certain drops when charged and in an electric field. This result occurs when drops of nearly equal size have a small relative velocity that is due to the electrical forces. When drops are highly charged in a strong electric field, we obtain relative velocities approaching an order of magnitude larger than the difference of the normal terminal velocities. Both of these situations result in an increase in the collision rate of such particles. We would also expect an equal number of paired drops for which the collision rate will be very small. However, the net effect on the growth equations and the rate of discharge between particles is affected much more strongly by the considerable increase in collision rate due to the former two situations. This is especially true in active thunderstorms with hail.

The calculations made by Atkinson and Sartor have led them to conclude that radio noise observed from convective clouds in Key West in the summer of 1963 (Sartor, 1964) does not originate in the emission from individual pairs of drops of the type observed in the laboratory. Therefore, the search must continue for the source of these small, rapid, pre-lightning discharges, since they must be important in the collection of charge from swarms of droplets.

A laboratory investigation directly related to this problem is being conducted by William Winn, using the rainshaft of the new NCAR building. Here a spray of highly charged drops impinges beneath the center of a charging ring and in the vicinity of a grounded electrode. The arrangement can be adjusted to induce breakdown from the drop swarm to the electrode, thereby simulating the transfer of charge from cloud drops in the pre-lightning process.

The second major information gap in our understanding of precipitation growth and cloud electrification is the lack of reliable observations, in various kinds of clouds, of charges of individual cloud and rain drops of various sizes. A reliable device is badly needed to measure both size and charge on the same drop. Winn is developing such an instrument. A pulse is obtained on an oscilloscope with a device that has a high voltage electrode to draw a spark discharge from an impinging drop; the pulse is a function of the size of the drop. The first model of this instrument appears to be giving reproducibly fast-rise pulses that are a function of the size of the drop. An induction ring will be added upstream to measure the charge of the measured drop. (Drops impacting on the induction ring will be blanked out electronically so that spurious information from their breakup or splatter will be ignored.) It is anticipated that this instrument will be used on a cloud physics aircraft and in the NCAR rainshaft.

Theodore Cannon is working on a cloud and raindrop camera, a device which will provide a useful in situ picture of drop distributions in clouds, undisturbed by the presence of aircraft or measuring probes. It will not, however, give simultaneous measurements of charge.

Cannon is using the small vertical wind tunnel in studies, designed after Telford's, of behavior of particles in a test section with different velocity profiles, to provide desired interaction and motion among drops. His studies should provide basic information on drop motions in electric fields, and results will be extrapolated to the larger vertical rainshaft (approximately 35 ft high). Along with the experiments conducted in the wind tunnel, Cannon is developing methods for measuring photoelectrically the fall speed and accelerations of charged drops in environments simulating those of natural clouds.

We have begun to adapt our conductivity, electric field, and particle-size measuring devices for a proposed cloud physics and dynamics airplane, for a program to obtain simultaneously information on microphysics and dynamics of clouds. These instruments use the latest solid-state electronics, and are highly reliable. Paul Eden has developed an electronic thermometer, using a diode as a sensor together with a self-contained solid-state amplifying circuit. It responds rapidly, giving a linear response over a range of more than 100°C. It will replace the temperature devices used at our high-altitude stations, and will be suitable for aircraft measurements.

On the larger scale, we are continuing our measurements, at Niwot Ridge and Climax, directed toward determining the relationship between world-wide atmospheric electricity parameters and thunderstorm activity, and we have started a third atmospheric electricity station at Lee Hill, about five miles north of the NCAR Laboratory. Instruments at Niwot Ridge and Climax seem to be operating reliably. At Climax, we measure only electric field and conductivity; other weather element information is supplied by Colorado State University, which maintains the station at Climax. On Niwot Ridge, temperature, wind speed and direction, electric field, positive and negative conductivity, and 145-H_2 radio noise are observed, and a solar cell identifies sunny and cloudy weather; the information is telemetered to the NCAR Laboratory on Table Mesa.

Strong emphasis on the importance of these measurements at high altitude has been provided by William E. Cobb of ESSA, who reports correlations identical to those of Reinhold Reiter in Germany, indicating that electric field and conductivity at high altitudes are related to major solar flare activity. Cobb suggested at the 1966 AMS meeting in Seattle that atmospheric electricity parameters, being also related to thunderstorm activity, indicate a solar-terrestrial linkage with world-wide precipitation. The same suggestion was made independently by Sartor at the same meeting, based on correlation between sporadic-E observed in Florida in 1964 and heavy thunderstorm precipitation, and the relationship that has been established between solar activity and sporadic-E. The data from Niwot and Climax also contribute to the international atmospheric electricity program of the IQSY.

Hail

Meteorologists are still trying to find out why some thunderstorms produce hail while others do not. Hail production apparently has to do with a special combination of updrafts, wind shear, and the availability of supercooled liquid water in the right form -- electrification processes may play an important part, also. There is hope that hail can be suppressed (under the right conditions) by introducing freezing nuclei into a thunderstorm; scientists in the Soviet Union and several other countries have claimed some success in hail suppression by such a technique. An NSF-sponsored joint effort called "Project Hailswath" was initiated during the summer of 1966 to investigate this and other possibilities for hail suppression. NCAR organized the initial meeting to consider this program in September 1965, and has played an active role in it ever since, with Guy Goyer and Patrick Squires as participants from LAS (Goyer, ed., 1966; Goyer, Howell, et al., 1966).

Goyer, Sonia Gitlin, and Myron Plooster have been investigating several aspects of hail formation, most of which have some bearing on the interesting hypothesis that shockwaves from lightning may either initiate freezing in supercooled drops or break up hailstones which still have liquid water entrapped in them. (This idea is the general basis for experiments in hail suppression that involve setting off high explosives in thunderstorms.) A number of uncertainties in this hypothesis need to be studied in some detail.

A calorimeter designed and built by Gitlin (Gitlin, Fogler, and Goyer, 1966) was used to measure the liquid water content of hailstones from several storms in Colorado, South Dakota, and Kitumbe, Kenya. In Colorado, 19 samples from three storms observed from May to August 1966 yielded liquid water contents ranging from 0 to 16%. In South Dakota, seven samples from two different storms occurring on 5 July contained from 0 to 8.3% liquid water. One interesting observation from the still small sample is the apparent steady decrease in liquid water content of hailstones from June to August. The largest stones collected in August contained no liquid water.

The 64 samples collected and analyzed in Kenya by Thomas Henderson, of Atmospherics Incorporated, Fresno, California, showed liquid water contents between 0 and 4%. The most interesting result from these data is the strong correlation between liquid water content and the qualitative observations of hardness: every hailstone qualified by the observer as hard contained no liquid water; every hailstone qualified as soft contained liquid water. No correlation, however, could be found between liquid water content and opacity or clearness of the hailstone. Clear and milky hailstones were found to contain equally variable amounts of liquid water. A paper describing this work is in preparation.

We plan to study the crystalline and other internal structures of hailstones collected in Boulder and by Project Hailswath personnel at Rapid City and vicinity, to try to determine growth mechanisms and conditions of formation. One of the most important things to measure is crystal fabric (preferred orientations), and to this end Charles Knight has developed a new, simple etching method (1966b).

Knight has analyzed stones from six hailstorms. C-axis radial orientations predominate, indicating that the hailstones grew by true crystal growth, not by collecting wet snowflakes. A number of other, independent lines of evidence lead to the same conclusion. In the larger stones, lobe structures are always found. The evidence, in all, suggests that on a small scale the icewater-freezing interface moves in a tangential rather than a radial direction, and that the mechanism is in principle much like that of icicle formation. Research on these hailstones will be completed in early 1967, and experiments on icicle formation will be started.

CRYSTAL GROWTH AND NUCLEATION IN WATER

Because water in its various states is everywhere in our environment, and because the transitions and interfaces between the frozen forms and liquid water are important in many of the phenomena that we are studying, we are making a special effort to learn more about how freezing is initiated and how ice crystals grow. Most of this work is being done in the laboratory, but some of it has also involved gathering hailstones and glacial ice for analysis. In these latter studies, ice structure may serve as a guide to the history of the ice formation. The work on hailstones is reported above (p. 80) in connection with other studies of precipitation processes.

Ice and Water Surfaces and Ice Crystal Growth

Knight has made experiments to test the commonly accepted hypothesis that water completely wets ice (in press). He found that water does not wet ice completely, which leads to a rather small revision of the value of the ice-air interfacial free energy, and to the conclusion that the interface between supercooled water and air is a preferred site for the nucleation of supercooled water. (The effect is probably extremely small, though.) The experiment gave 12° as a minimum value for the contact angle of water on ice. A better, more quantitative experiment will be performed, using the supposition that, if the contact angle is not zero, there should be a barrier to the nucleation of water on an ice surface. (In other words, it should be possible to superheat a clean ice-air interface.)

New and improved apparatus for generating negative crystals was completed during the summer (see Knight and Knight, 1965). This project will last several years. Knight traveled to Juneau, Alaska, in the early fall, to collect ice crystals from Mendenhall Glacier for this work; the internal structure of glacier crystals is far more perfect than that of crystals grown in the laboratory by known methods. Work on the theory of crystal equilibrium form is in progress.

The difficult and interesting problem of curved growth of ice and other crystals from supercooled melts at substrate surfaces continues to be the subject of some thought and experiment (Knight, 1962). This year, for the first time, Knight produced curved dendrites in bulk solution, proving that the presence of a substrate surface is not a necessary condition for their formation.

Knight also studied the development of preferred crystal orientations in the thickening of ice sheets, and found preferred intergrain orientations in polycrystalline ice grown in the laboratory from salt water (Knight and Knight, 1966). This development casts a certain doubt on a previously proposed mechanism (Knight, 1966c) for producing intergrain orientation preferences in fresh-water ice.

In the belief that wide experience with ice phenomena is a good thing per se, and because it is an interesting problem and relates to prehistoric climatic changes, Knight has worked further on ice-cored rock glaciers and moraines in the Rocky Mountains, with James Benedict of the Arctic and Alpine Research Institute of the University of Colorado. The problem posed in this research is whether any given ice core is a consolidated snow bank covered by avalanche debris (and thus protected from melting), or whether it is an actual remnant of a former glacial advance. Several specimens of ice from a deep gorge cut in the ice core under the

Arapahoe rock glacier in the summer of 1966 have been collected and are being studied in detail in the NCAR cold room.

Dynamic Nucleation of Ice Crystals in Water

The 1965 Annual Report of the work by Guy Goyer and his colleagues stated that nucleation of freezing in supercooled water by mechanical means appeared intimately related to the dynamic response of bubbles to mechanical disturbances. Further work has confirmed this relationship for all our experiments on bulk samples of supercooled water. Considerable progress has been made in evaluating microphysical processes that may provide a mechanism for nucleation in such situations. It is less certain whether these processes can explain the results of experiments on shock-induced freezing of clouds of supercooled droplets, such as the wintertime experiments on the plume of Old Faithful geyser in Yellowstone National Park by Goyer.

J. D. Hunt and K. A. Jackson, of Bell Telephone Laboratories, studied the growth and collapse of cavitation bubbles in samples of supercooled water contained in sealed, evacuated glass tubes. They reported in 1966 that the growth of a bubble in a supercooled liquid never triggered freezing, whereas collapse of a bubble always did. Sonia Gitlin has used high-speed motion photography to observe the dynamic behavior of bubbles and the onset of freezing in such a system. Unequivocal separation of the growth and collapse of bubbles, which Hunt and Jackson had reported, was not possible. Freezing usually resulted from an oscillatory period of successive collapses and regrowths of a bubble. The first observable ice crystals invariably appeared near the bubble-water interface; it was not possible, however, to ascertain at which stage in the life history of the bubble the actual nucleation of freezing occurred.

San San Lin demonstrated the possibility of triggering freezing in supercooled water by seeding with ice crystals formed by adiabatic expansion of the gas phase. A bulk sample of supercooled water was contained in a vessel filled with air under pressure and sealed with a cellophane diaphragm. Upon rupture of the diaphragm, the air expanded and cooled adiabatically, and water vapor condensed. Under proper initial conditions of temperature and pressure, the water sample froze also. The results are consistent with the attainment of a threshold temperature of -35^{o} to $-40^{o}C$ in the gas phase, at which temperature homogeneous nucleation of freezing in water droplets occurs. Ice crystals thus formed then settle and nucleate freezing of the water sample.

Burton Schuster suggested that cooling of the gas phase within a growing cavitation bubble might also be sufficient to permit homogeneous nucleation of ice crystals, which would then seed the bulk sample. Schuster and Plooster developed a theoretical model and computer program to test this hypothesis. Measurements of the actual growth rates of cavitation bubbles were taken from Gitlin's motion pictures. Early computations have shown sufficient cooling and water vapor concentration within a bubble to produce large concentrations of ice crystals during growth of the bubble. A motion picture study of the time required for ice crystals to become visible, after a freezing center is introduced into a supercooled water sample, also agrees with nucleation during the growth cycle of a bubble. However, there are still experimental and theoretical uncertainties, and further work is under way.

Lin performed other short-term experiments adding supporting evidence for the close relationship between bubbles and freezing. She made a series of tests to observe the formation of bubbles and triggering of freezing at the surface of smooth or rough, hydrophilic or hydrophobic bodies which moved through supercooled water. She observed that water which freezes at $-8^{o}C$ when undisturbed can be made to freeze at temperatures only slightly below $0^{o}C$ by the slight movement of a rough metallic surface, such as a fine-wire thermocouple junction. On the other hand, a smooth polyethylene or glass rod only triggers freezing by strong agitation or by momentary contact with the wall of the container. These results are consistent with the generation of cavitation bubbles at the interface between the water and the foreign body. High speed photography will be used to study the generation and life cycle of these bubbles.

The role of nascent air bubbles or cavitation bubbles in triggering the freezing of bulk supercooled water provides a plausible explanation also for our previous laboratory results.

In shocktube experiments on bulk water, we found that the thermocouple used to measure temperature and detect freezing of supercooled water samples played an essential part. When no thermocouple was immersed in the sample, no freezing resulted at shock wave intensities that produced freezing in similar samples containing a thermocouple. Mechanical displacement of the thermocouple with respect to the water by the shock wave presumably gave rise to the formation of cavitation bubbles at the thermocouple-water interface. The effect of pressure changes alone was never observed to initiate freezing.

At Yellowstone, very weak shock waves triggered freezing of supercooled droplets in the plume of Old Faithful geyser. The substantial amounts of dissolved gases in Old Faithful water may serve as nuclei for the formation of cavitation bubbles under weak stimulation. Foreign solids or microscopic air bubbles in cloud droplets might play the same role in triggering freezing of hydrometeors under the influence of shock waves from lightning discharges. Another possibility, however, is that enhanced droplet collision and shattering under the effects of shock waves may also serve to nucleate the ice phase.

Plooster studied shattering and freezing of single free-falling supercooled water droplets subjected to shock waves of known intensity, in a shock tube. He sought to detect ice in the fragments of shattered droplets, by photography and by collecting fragments in a supercooled sugar solution. Preliminary results, based primarily on photographic evidence, appear to indicate that frozen fragments are produced under certain conditions. Confirming evidence from direct counts of crystals captured in supercooled sugar solution was sought shortly before the move to the NCAR Laboratory, but insufficient data were collected to warrant firm conclusions at this time. A new shock tube, designed to eliminate some of the experimental uncertainties in the previous results, is being built.

To determine more precisely the strength and decay of shock waves generated by lightning discharges, roughly estimated by Goyer from a detonation model, Plooster has developed from first principles a theoretical model of this phenomenon. Field measurements of the quantity and rate of flow of electrical charge through a lightning discharge column, combined with existing theories of electrical conductivity of ionized gases, are used to determine the electrical energy input to the discharge column. The resulting aerodynamic disturbances are determined from the standard equations of gas dynamics. The model is now being programmed for the Control Data 6600. The goal of this work is an accurate theoretical curve of the strength of the shock wave resulting from a lightning discharge as a function of the distance from the discharge and of the electrical characteristics of the discharge. Such a result will permit a more accurate evaluation of the range of action of aerodynamic effects of lightning discharges on hydrometeors.

CHEMISTRY OF TRACE GASES

With our current concern over man's pollution of the atmosphere -- and a very legitimate concern it is -- there is a tendency to overlook the fact that the earth's atmosphere has always been a chemical mixing pot. Hundreds of thousands of tons per year of organic materials are released by vegetation, several thousand tons per day (the exact amount is still uncertain) of meteoritic debris are added to the upper atmosphere, and volcanoes continue to add their spectacular and highly variable burden of gas and debris. The main concern of the atmospheric chemist is to find out where the sources and sinks of the various aerosols and trace gases are, how aerosols and trace gases are transported by winds and turbulence after they leave their sources, and how the gases and aerosols interact with each other and with solar radiation.

The mechanisms that produce several kinds of aerosols, such as haze, smog, and the sulfate particles of the stratosphere, appear to be a kind of precipitation of trace gases. Furthermore, aerosols in the atmosphere probably have a catalytic effect on many chemical and photochemical processes by providing a surface on which reactions can take place. Although we have chosen to describe our work on aerosols and gases separately, it should be clear that we think of them as part of the same subject.

Aldehydes in Smog

Aldehydes are one of the most important classes of organic substances (after hydrocarbons) emitted into photochemical smog. Formaldehyde and acrolein contribute to the eye irritation produced by such smog, while other aldehydes probably take part in the photochemical reactions. In the formation of photochemical smog, the reaction between atomic oxygen and various organic substances is important. Since relatively little is known about reactions of atomic oxygen with aldehydes, Richard Cadle and Dr. Jack Powers (a visiting scientist from Ripon College) studied the reaction of atomic oxygen with acetaldehyde. This aldehyde was chosen because it is in many ways typical of smog aldehydes, and because its reaction with atomic oxygen has been studied to some extent in Russia (Avramenko and Kolesnikova, 1964) and Canada (Avery and Cvetanović, 1965) but with highly conflicting results.

The same type of high-velocity flow system was used for this study as was used for previous investigations of the reactions of atomic oxygen with methane, butane, and sulfur dioxide (see 1965 Annual Report).

The rates for this reaction (investigated at various temperatures, concentrations, and total pressures) were found to be such that aldehydes would be expected to take an important part in formation of photochemical smog, but not as great a part as the more reactive of the hydrocarbons.

The rates obtained agree quite well with relative rates obtained (using entirely different methods) by Avery and Cvetanović, but are about two orders of magnitude higher than those obtained by Avramenko and Kolesnikova. The end products of the reaction were found to be methane, carbon monoxide, carbon dioxide, and water. While the nature of these products sheds light on the reaction mechanism, only the intermediate products would be expected to contribute to the unpleasant effects of smog.

Hydrocarbons and Atomic Oxygen

The reactions of ground-state atomic oxygen $O(^3P)$ with hydrocarbons are of particular significance where the results of such studies may be extrapolated to conditions existing in the 40-70 km region and the polluted lower troposphere. The sources of atomic oxygen in these regions are well known: O_3 and O_2 in the former, and NO_2 in the latter. The fate of hydrocarbons in these regions, however, is not so well understood and is a subject for further investigation.

Cadle and Eric Allen have extended their studies of the reactions of ground-state atomic oxygen with methane and butane in discharge flow systems, to obtain a better understanding of the mechanism of hydrocarbon decomposition and the build-up of products relatively stable to attack by atomic oxygen. A specific problem is to determine the relative contributions, if any, of the three proposed primary steps in the oxidation of methane.

$$O(^3P) + CH_4 \rightarrow CH_3 + OH$$
$$\rightarrow CH_2 + H_2O$$
$$\rightarrow CH_2O + H_2$$

Such knowledge is important in predicting secondary reactions and their effect on the overall mechanism of oxidation. The high stoichiometry of these reactions $\left[\frac{d\,[O]}{d\,[\text{HYDROCARBON}]}\right]$, coupled with the accelerating effect caused by adding molecular oxygen to the system, suggests that a free radical chain reaction may be important and that this type of reaction may contribute to an accumulation of oxygenated products in the 40-70 km region. Qualitative information has been obtained on the formation of hydrogen, carbon monoxide, carbon dioxide, and formaldehyde, and quantitative studies are in progress.

Allen has searched for other sources of oxygen atoms, using a microwave discharge cavity. A third source to complement the two already being used -- the direct electrical discharges in oxygen and the titration of active nitrogen with nitric oxide -- would be advantageous as an independent means of checking previous results and establishing with greater certainty that the reaction being observed is solely due to the attack of ground-state atomic oxygen on the hydrocarbon. At present, a nitrous oxide discharge appears to be promising in this respect and yields oxygen atoms efficiently. Further studies are being made to determine the mode of decomposition of nitrous oxide for the purpose described above.

Photo-oxidation Mechanisms in Polluted Atmospheres

Eric Allen and Kent Bagley have designed, constructed, and tested a static photolytic system which incorporates the latest techniques applicable to such systems. Flexibility of design has greatly increased their capacity to study various reactions and their experimental data output. The gas-sampling system for chromatographic analysis (Allen, 1966) permits them to analyze the reaction mixture at frequent intervals during the course of an experiment.

Two studies are under way at present: (1) photolysis of nitrogen dioxide-hydrocarbon mixtures, and (2) photolysis of free radical sources in the presence of the oxides of nitrogen. Both investigations pertain directly to processes occurring in photochemical smog and air pollution, and are designed to answer the following fundamental questions:

- To what extent are free radical processes involved in smog production?

- What types of free radicals are most important?

- How does the presence of hydrocarbon accelerate the oxidation of nitric oxide to nitrogen dioxide?

- Why are the observed oxidation rates of hydrocarbons significantly larger than those predicted on the basis of known rates for atomic oxygen-hydrocarbon reactants?

- What products of these reactions could be physiologically harmful to human beings and plants?

Photolysis of nitrogen dioxide as a source of atomic oxygen is closely related to discharge flow system studies. Stationary concentrations of atomic oxygen achieved in the former, however, are several orders of magnitude smaller than in the latter, and are more realistic in terms of atomic species concentrations found in a polluted atmosphere. The rates of formation of products are being used to follow the course of the reaction, to obtain relative rate data on individual steps, and to formulate an overall mechanism. Evaluations of the effects of varying wavelength, intensity and time of irradiation, and temperature are expected to provide sufficient information to enable at least partial theories to be postulated to account for the complex processes involved. The preliminary results of this work were presented at the International Conference on Photochemistry in Tokyo in 1965.

As a natural extension of these studies, the reactions of free radicals (mainly methyl) with oxides of nitrogen are also being investigated. To start with, simple mixtures are being studied, and as a better understanding of their reactions is obtained investigations will be extended to more complex mixtures which will more closely simulate the conditions observed in polluted urban air. An exhaustive analysis has been made of products of the photolysis of acetone-nitric oxide mixtures; the products include nitrogen dioxide, nitrous oxide, acetic acid, methyl acetate, formamide, nitromethane, biacetyl, methane, and ethane. The effects of varying reaction parameters are being studied at present.

Methylene and Production of Tritiated Methane

Since it began in 1963, the photochemistry program under Richard Cadle has been investigating various aspects of the chemistry of atmospheric methane. For example, research reported in the 1965 Annual Report demonstrated that the reaction of methane with atomic oxygen is probably the main sink for methane in the stratosphere and mesosphere (see also Cadle and Powers, 1966).

This work is carried out in close cooperation with investigations of atmospheric methane in the isotope geophysics program (see p. 87). Edward Martell, program scientist for the latter program, suggested (1963) that tritiated methane (CH_3T) in the atmosphere results from tropospheric exchange of methane with tritiated hydrogen (HT) which has mixed downward from the stratosphere. He proposed that the exchange occurs either by way of methylene (CH_2) produced from methane by electrical discharges, or by bimolecular exchange of CH_4 and HT.

At Martell's suggestion, Cadle has investigated the possibility that some atmospheric constituent reacts preferentially with methylene, preventing its reaction with HT. Methylene was produced by irradiating ketene with ultraviolet light in a quartz reaction vessel. Analyses were made using mass spectrometry, infrared spectrometry, and gas chromatography. Cadle found that nitric oxide, which would be produced in the atmosphere by any process that might be expected to produce methylene, does interfere. The reaction of methylene with nitric oxide probably produces atmospheric organic nitrogen compounds, but it is unlikely that they are of particular geophysical significance.

Alkali and Alkaline Earth Metals in the D-Region

The sources and the chemistry of sodium and other alkali and alkaline earth metals in the D-region of the ionosphere are highly controversial subjects. Both sea salt and extraterrestrial particles have been suggested as the source of the sodium atoms, and it is not at all clear how the sodium compounds (chloride, silicates, etc.) are converted to atomic sodium. Keith Schofield (visiting scientist from the University of California at Santa Barbara), Allen, and Cadle are investigating the chemistry of sodium (and other alkali and alkaline earth metals) in the D-region. They are seeking answers to the following questions:

- What is the most likely mechanism (mechanisms) for the formation of free sodium from sea salt or from silicates?

- What are the most likely mechanisms of sodium atom excitation in the night airglow?

- Do reactions of any of the metallic atoms with atomic oxygen produce ionization?

- Is there any basis in their chemical properties for decision as to whether sea salt or extraterrestrial particles constitute the main source of the uncombined alkali metals?

Schofield, Allen and Cadle spent most of 1966 constructing and assembling equipment. They also attempted to determine whether atomic oxygen reacts with sodium chloride to form NaO, which might be a step in the formation of atomic sodium. Results to date indicate that this reaction, if it occurs at all, is very slow.

Survey of Rate Constants

While assembling the equipment for the above study, Schofield made a literature survey of rate constants of chemical reactions important in the natural atmosphere (in press).

Energy Distribution of Some Ionospheric Species

The calculations made by many aeronomists depend on the use of rate constants for atmospheric reactions that have been determined in the laboratory. Such laboratory studies are usually undertaken under conditions such that the reacting species have a Maxwellian distribution of energies, i.e., they are "thermalized." Rate constants for reactions whose rates are appreciably affected by temperature (i.e., that have appreciable activation energies) should only be used when the reacting species have Maxwellian distributions of kinetic energies.

In the ionosphere many processes occur that produce non-Maxwellian distributions. For example, the photolysis of oxygen (O_2) by solar radiation more energetic than that required to break the bonds produces atomic oxygen which may have very high kinetic and even electronic energy. Collisions with other atoms and molecules will eventually thermalize the atoms, but they may react chemically before thermalization is complete. Furthermore, the thermalizing collisions may themselves produce other excited species.

Kwang-Sik Yun (visiting scientist from the National Research Council of Canada) is undertaking a theoretical study in an attempt to determine whether certain important reactions at various levels in the ionosphere are markedly perturbed by non-Maxwellian energy distributions. The reactions that seem most likely to be perturbed are bimolecular reactions involving molecules and only neutral species. Slightly endothermic reactions involving charged species are also likely to be greatly affected by the energy distribution.

We hope that this study will indicate whether serious errors are being made in calculations of concentrations of various atmospheric species, by ignoring the distribution of energies.

Yun has also been serving as a consultant to Charles Knight in studies of curved ice crystals.

Isotopic Composition of Water Vapor

Studies of the tritium and deuterium content of water vapor profiles have been extended by Dieter Ehhalt to include monthly profile collections over the eastern Pacific as well as over Scottsbluff, Nebraska. Water vapor samples are collected from NCAR aircraft by passing air through special U-tubes held at dry ice temperature.

A limited investigation was carried out to determine deuterium and tritium contents of hailstones and their variation with hailstone size (and with radial depth for large hailstones).

Deuterium (D) and tritium (T) analyses were performed on small hailstones collected on 7 June 1966 in Boulder, Colorado, and on one big hailstone collected on 5 July 1965 in Chadron, Nebraska. Although the stones from 7 June 1966 were sorted into five size ranges the T-content was found not to vary with size. From the large stone collected 5 July 1965, slices taken at different radii were analyzed. While the total relative T-content of the small stones does not vary with size, the successive layers of the large stone show large variations in T-content, anticorrelated to variations in the D-content. The especially high T-content in the 5-mm inner core suggests that the stone reached high altitudes in its early stages of formation and fell back into the lower parts of the updraft, where it acted as a hail embryo. This supports Ludlam's hypothesis, which claims that large hailstones can only be grown by repeated ascents. It appears that large hailstones may be quite active in transporting radioactive debris downward from high altitudes.

With the cooperation of Dr. Vaughn Bowen of Woods Hole Oceanographic Institution, oceanic water vapor samples have been collected on an Atlantis II cruise. These samples will be analyzed for tritium and deuterium to determine the vertical transport of tritium and water vapor in trade-wind areas.

Gas Chromatography

Leroy Heidt has continued and extended his studies of the vertical profile distribution of methane, hydrogen and other atmospheric trace gases. Using NCAR aircraft, vertical profiles of air samples have been collected in evacuated stainless vessels over Scottsbluff, Nebraska, Death Valley, and the eastern Pacific.

The samples are measured using an analytical gas chromatograph with an RF detector, capable of resolving Ne, H_2, O_2, N_2, CH_4 and CO. Reference standard gas mixtures with trace concentrations of Ne, H_2 and CH_4 in helium have been obtained from the U. S. Bureau of Mines. Results of aircraft sample profiles will be evaluated in the near future, using an improved computer program which incorporates the standard gas mixture calibration data.

Heidt has also developed an improved chromatograph detector, using direct current under low pressure, which provides about one order of magnitude greater sensitivity than the RF detector. In addition, he will test silica gel and "porapak" column packings because they should provide better resolution of the CH_4 and N_2 peaks and also allow measurement of atmospheric NO, NO_2 and CO_2.

Radioactive Tracers

Two years of measurements of Ce^{144} and Sr^{90} in tropospheric air samples, collected between March 1964 and March 1966, have been completed by Charles Watkins and Edward Martell. These and related measurements obtained during atmospheric nuclear test moratorium periods show variations related to large-scale seasonal and annual variations in stratospheric mixing and in the stratosphere-troposphere exchange process. In evaluating these results, Martell reviewed tungsten-185 tracer studies done elsewhere and noted the presence of a HARDTACK test tungsten-185 layer at middle stratospheric levels, heretofore unreported. A report on the stratospheric transport of this high-altitude tungsten layer is in preparation. Martell and Stewart Poet have begun measurements of the long-lived daughters of radon, lead-210, bismuth-210, and polonium-210, which hold promise as tracers for aerosol residence times in the troposphere and as atmospheric tracers up to about 20 km.

Irving Blifford has investigated statistical techniques suitable for the analysis of large collections of atmospheric radioactivity data and chemical pollution data. He has used IGY 80th meridian radioactivity data (resulting from a program in which he wâs personally involved) for testing analysis procedures. Computer programs have been written to perform spectral and cross-spectral analyses and to compute certain spectral functions. In addition, a program has been devised for using factor analysis techniques from which contours of the factors can be plotted on the dd80. This method has been applied to pollution data obtained by the U. S. Public Health Service, and a paper on the subject is in press. Examination of radioactivity data using these techniques has only just begun and it is too early to say whether a worthwhile reduction in complexity can be achieved. Results from a few preliminary analyses of the 72-station Public Health Service network look hopeful and, depending on the degree of success obtained, more sophisticated statistical procedures will be employed. The necessary mathematical theory has been worked out by Dr. N. R. Goodman, who acted as a consultant in this work.

ENCAR Rocket Sampler

Under National Aeronautics and Space Administration (NASA) Contract NASr-224, the isotope geochemistry program group, under the direction of Edward Martell, has undertaken to design and develop a rocketborne cryogenic air sampler for use over a wide range of altitudes above 40 km, the practical ceiling for balloon systems, and to construct two samplers for the Aerobee-150 rocket for the investigation of trace gases, aerosols, and dust in the upper stratosphere and lower mesosphere. Edward Denton has played a major part in this project. After construction, the sampling systems will be subjected to detailed engineering tests and experimental evaluation by NCAR, to liquid hydrogen cryogenic tests by the Cryogenic Engineering Laboratory of the National Bureau of Standards, and to flight tests by the NASA Goddard Space Flight Center. After flight and recovery at White Sands Missile Range by NASA, the air samples and sampler units will be returned to NCAR for detailed analysis.

The first prototype rocket-borne cryocondenser, now under construction, has been designated the ENCAR-I Sampler (ENclosed Cryocondenser for Air Recovery). Design details of the ENCAR-I system, heat exchanger model computations, related experimental condensation studies, and other design criteria are reported in NCAR Technical Note 18 (Denton, et al., 1966), with a discussion of experimental plans.

During 1966 the design of the ENCAR-I system was completed, fabrication techniques were worked out, and two sampling units were built. Valuable assistance was provided by Dr. R. B. Jacobs (R. B. Jacobs Associates, Boulder, Colorado), consultant on heat exchanger and component design, by A. F. Schmidt and J. Hord of NBS for cryogenic studies, and by Dr. Adolph Busemann (University of Colorado), who acted as aerodynamics consultant for this program. Otherwise, all work on the sampler design and fabrication has been carried out within NCAR, with able assistance from the NCAR Design and Prototype Development Facility.

The present schedule calls for engineering and cryogenic tests and experimental evaluation of the samplers in the first quarter of 1967, and two Aerobee-150 sampling flights at White Sands later during 1967.

Trace Gases in the Lower Atmosphere

James Lodge and his associates have been concerned with studies of the trace gas content of unpolluted air and rainwater, and have made observations in many parts of the world. In this work it has been necessary to perfect a number of new techniques for field sampling and analysis (Lodge and Frank, 1966).

John Pate and his group have continued the laboratory investigation of available techniques for trace gas analysis and their adaptation for use in the unpolluted atmosphere. They completed their studies of the use of hypodermic needles as critical orifices for air sampling, which permits great simplification of field equipment (Lodge, Pate, et al., 1966). They encountered substantial difficulty with the most accepted method for hydrogen sulfide determination, but have worked out a modified technique which seems to meet their requirements. They have also devised an improved method for the conversion of nitric oxide to nitrogen dioxide for subsequent determination, and a method for handling small amounts of nitrogen dioxide (Pierrard and Lodge, 1966). Lodge and Pate have prepared a definitive evaluation of the state of the art of atmospheric analysis, which will be published in 1967.

With the move to the NCAR Laboratory, Pate has designed a highly flexible facility for producing accurately known test atmospheres. Construction will be completed early in 1967 and should allow us for the first time to compare all of our analytical techniques against an absolute standard in the concentration range that we are studying in the atmosphere. This apparatus will probably be unique, since the only other laboratories known to be developing such setups are concerned with the much higher concentrations experienced in polluted atmospheres. Lodge reviewed this general subject for a monograph on air pollution to appear next year.

Our largest single field operation continues to be the collaborative study with the U. S. Army Tropic Test Center in and around the Panama Canal Zone. Lodge and Pate (1966) have published a preliminary report of the findings there. Two major sampling periods during the year were the dry season of February and the first peak of the rainy season in May and June. Pate, Arthur Wartburg, Evelyn Frank, Miles LaHue, and Lodge were all involved in varying degrees, and Dr. Reinhold Rasmussen of Walter Reed Army Hospital collaborated. Tropic Test Center personnel are continuing to make regular measurements of aldehyde and nitrogen dioxide concentrations. Our model of the behavior of the tropical atmosphere with regard to trace contaminants is now sufficiently good to allow us to design definitive experiments.

The following conclusions about the Panama region appear warranted in the light of the available data:

• Hydrogen sulfide is present in significant amounts only immediately after the onset of rain after the dry season.

• Formaldehyde and nitrogen oxides are present in amounts and in locations consistent with the "Went hypothesis" that smog-like reactions are occurring between the nitrogen oxides and unsaturated organics from vegetation.

• Sulfur dioxide appears to have a different source.

In addition, Dr. Rasmussen was able to make very interesting studies concerning the interdependence of epiphytes and trace organics in the air.

At the end of the year, a contract was negotiated between the Army Research Office and NCAR to permit a far more intensive series of studies next year. Substantially the same group of people will be involved, and LaHue will spend a significant portion of his time in the Canal Zone. The spectrum of substances investigated will be expanded.

William Fischer observed and measured a similar spectrum of trace gases in Antarctica, the least biotic area of the world. Fischer's preliminary reports indicate that, away from the center of human activity at McMurdo, nitrogen oxides or sulfur oxides, if they are present, do not exist in sufficient quantity to be measured on equipment sensitive enough to find them anywhere at mid-latitudes. However, formaldehyde appears to be present in all samples taken on the ice, though it is absent from samples in the dry valleys. It is quite possible that this is another manifestation of the observation made a few years ago by Alexander Goetz, that a snow surface is a prolific source of aerosols whenever the sunlight strikes it. Fischer has now been instructed specifically to look for variations in formaldehyde production with degree of insolation.

With data coming from the tropics and Antarctica, it seems reasonable to study as well the comparatively unpolluted temperate atmosphere. Trace gas measurements were made at sea near San Nicolas Island from the University of Southern California oceanographic vessel, Velero IV. Data were fewer than hoped for because of an extended Santa Ana wind. However, the wind changed on the last day and it appears measurements then were made in fresh marine air. Both nitrogen dioxide and formaldehyde were detected. This information, matched with similar measurements at the shore on the Atlantic side of the Panama Canal, suggests strongly that the ocean as well as the land can be a source of material for the type of reaction postulated by Went. The chemistry of the reaction over snow, which can apparently occur in the absence of nitrogen oxides, is less clear. However, it seems to produce formaldehyde and particulate matter in much the same way. Further studies will obviously be necessary. On a previous sea trip Gladys Sturdy and Fischer (1966) measured the surface tension of the sea in and out of natural "slicks."

We are just beginning a collaborative study with the Bishop Museum in Honolulu. The Museum operates a large insect collecting scope on an aircraft which flies out of the Pacific Missile Range Base at Point Mugu, California. There is considerable excess space in this trap, and they are flying NCAR devices in it. We plan to collect both aerosols and trace gases during flights from Point Mugu to southern South America. There is a considerable east-west component in the flight path, but samples taken along this course can still be treated as a meridional section for purposes of studying the mixing of trace atmospheric components in and out of the tropics. The specialized equipment was developed jointly by Arthur Wartburg and the NCAR shop. Samples are being taken by Eugene Holzapfel of the Bishop Museum staff.

Rainwater Analysis

In the past, the various inorganic compounds of nitrogen in precipitation have frequently been analyzed separately. Results generally show that, even with the addition of preservative to rainwater samples, the relative amounts of ammonia, nitrite, and nitrate reflect the age of the samples rather than the amounts initially present in the rainwater. Therefore, when a new technique for ammonia was developed by Allan Lazrus, he undertook the development of a technique to reduce all fixed nitrogen to ammonia for determination in toto. The method has now been validated and will be published shortly. Lazrus also acquired an atomic absorption spectrometer which will permit, for the first time, good analyses of the patterns of metal ions in the precipitation samples.

The U. S. Weather Bureau and the Public Health Service continue to make routine collections of precipitation from approximately forty stations. Chemical analysis of the samples is being done at NCAR by Lazrus and Elizabeth Lorange. We are developing computer programs to process the resulting data, and we plan to continue the collection until a significant sample of data is in hand, or until some other laboratory agrees to take on the analysis.

SCATTERING OF ULTRAVIOLET AND VISIBLE RADIATION; OPTICAL PROBING TECHNIQUES

Radiation in virtually every part of the electromagnetic spectrum plays some role in the atmosphere. We are concerned with radiation in the visible and ultraviolet because the theory describing the multiple scattering of light in an atmosphere which contains absorbing and emitting gases is not yet adequate to allow us to treat many practical cases. We also hope to develop some indirect probing techniques to exploit the scattering of short-wave radiation; this will lead to the development of both ground-based and satellite-borne instruments.

Atmospheric Optics and Radiative Transfer

Mathematical inversion of spectral radiation measurements to obtain indirect observations of atmospheric properties is an intriguing possibility, but it poses formidable theoretical and experimental problems. On the one hand, a mathematical model of the atmosphere must be of high fidelity, giving proper recognition to emission, absorption, and scattering by all atmospheric constituents at the wavelengths concerned. On the other hand, measurements must be of extremely high accuracy, since small random errors in measurements are most damaging to the inversion procedure. We have put much effort into this type of mathematical study during 1966.

A proposal by Jitendra Dave (with Donald Heath of NASA as co-investigator) to determine the spatial distribution of ozone from measurements of solar ultraviolet radiation backscattered by the terrestrial atmosphere, has been formally accepted by NASA, and instruments will be flown on the Nimbus-D satellite, probably in late 1969. In preparation for this experiment, Dave and Carl Mateer carried out an extensive preliminary feasibility study (in press) on the determination of total atmospheric ozone content from satellite measurements of backscattered radiation. Their work emphasizes the importance of the albedo of the underlying surface (cloud or ground) in such determinations. Since virtually no information is available on the ultraviolet reflectivity of natural surfaces, a program has been developed, in cooperation with NASA, to make such measurements from NASA's Convair 990 aircraft during 1967. Theodore Noel and Donald Heath of NASA have prepared specifications for the instrument (a double monochromator) proposed for Nimbus-D and have requested design and fabrication proposals from industry. Paul Furukawa, Philip Haagenson, and Mary Jo Scharberg have compiled a composite high-resolution solar spectrum from 2080 to 3600A. This spectrum is being used in further numerical studies designed to help in the selection of wavelengths at which the satellite observations will be made. Their report will appear as NCAR Technical Note 26 early in 1967.

To gain additional experience in this area, Dave and Mateer have started a cooperative study with Charles Barth, Laboratory for Atmospheric and Space Physics, University of Colorado. Barth has been involved in an airglow experiment with an ultraviolet monochromator on OGO II and another on OGO IV, the latter being scheduled for launch in 1967. Preliminary analysis of OGO II data will commence shortly, with a view to seeing what information about vertical ozone distribution can be inferred from the measurements. In addition, a program of rocket, balloon, and ground-based measurements of ozone amount and vertical distribution has been organized to coincide with overpasses by OGO IV. We hope thus to establish a fairly reliable baseline for evaluation of OGO IV data at other places and times.

Dave and Mateer have joined with Larry Dunkelman and Dennis Evans of NASA in proposing a manned spacecraft experiment for the Apollo series. The purpose of this experiment is to observe and explain the banded colors in the twilight sky above the horizon, as observed and photographed by Gemini astronauts and Soviet cosmonauts. We hope to deduce something about the vertical distribution of large scattering particles and, possibly, of ozone from filter photography of twilight from spacecraft.

Claire Sheldon has continued to supervise the design and development of a double monochromator for determination of vertical ozone distribution from the ground or from aircraft. Mechanical design and fabrication of the monochromator is complete, except for machine work on a major casting and three small sub-assemblies. Preliminary assembly will start in January or February 1967. The grating rotator system has been delivered and partially tested. Design of the electronic control system is nearly complete, and fabrication of logic boards and electronic sub-assemblies is about 75% complete. Integrated tests of the electronic control with electromechanical sub-assemblies will start in early 1967. The control system should be ready for final assembly and packaging by the time preliminary mechanical assembly is started. Following this, final mechanical and optical assembly, alignment, calibration, and field mounting will begin.

Dave and Furukawa (1966a, 1966b) and Dave and Hugh Walker (1966) have published their extensive theoretical-numerical works, largely completed in 1965, on the radiative transfer of primary and multiply-scattered solar radiation in a plane-parallel, nonhomogeneous Rayleigh atmosphere.

Dave and Furukawa will next evaluate the effects of Rayleigh scattering and Lambert ground reflection on solar energy absorbed by ozone in the earth's atmosphere (in press). In an extension of this work, they have made a preliminary investigation of the problem of scattering by haze (Mie particles) in the presence of ozone absorption, and they have developed equations for the case where polarization is neglected. The solution of these equations, which will involve successive iterations of the auxiliary equation, will be coded for the computer in 1967.

A cooperative experiment was undertaken with Julius London of the University of Colorado and Arlin Krueger of the Naval Ordnance Test Station, China Lake, to measure the ozone amount above 7 mb over Brazil during the 12 November solar eclipse. Krueger's optical ozonesonde was to be flown on a constant-level balloon drifting across the path of totality. The purpose of the experiment was to examine the agreement between measurement and photochemical theory predictions of high-level ozone concentration changes when solar radiation is cut off by an eclipse. The experimental work was coordinated by Furukawa, with the assistance of Robert Kubara of the Scientific Balloon Facility. Unfortunately, a balloon failure occurred at the critical time and no useful observations were obtained during the eclipse.

Laser Atmospheric Soundings

We have analyzed some of the laser backscatter data gathered at Sacramento Peak in the summer of 1965. A series of 13 probings made over a period of 6 hr revealed the altitude, thickness, and temporal variations of several layers of cirrus clouds, directly overhead but invisible to the naked eye. The altitude of the lower layer was verified by Holloman Air Force Base balloon soundings. The study showed the laser probing system entirely adequate for ranging of water clouds.

Robert Watson analyzed several oscilloscope photographs of the return signal taken on clear, moonless nights, with the hope of detecting the 20-km dust layer. The analysis of the soundings made at 2317 on 30 July 1965 revealed pulses which presumably correspond to five different dust layers. They are distinct from noise pulses, since they reoccur after identical delays on three successive soundings, four seconds apart. The analysis was, however, made extremely difficult by the low signal-noise ratio. A first layer 0.5 km thick was found at 11.0 km altitude. The second layer, possibly corresponding to the tropopause, was 0.9 km thick and was at an altitude of 11.5 km. A dual layer appeared at 13 km and at 13.8 km; the small amplitudes of these peaks on the return traces, however, make them uncertain. Finally, a broad layer was detected between 16 and 19 km. Since all these peaks reoccur on several successive traces, they are assumed to correspond to real signals and not to random noise.

We believe that early difficulties with laser soundings are associated, in part, with the interference of the long-lasting fluorescence pulse, inherent to the laser output, with the return signal. Scattering of fluorescence radiation by low-altitude scatterers increases the background illumination and consequently decreases the signal-to-noise ratio of the return signal from high-altitude scatterers. We have therefore designed and built a system to reduce the amplitude and duration of the fluorescence pulse. The method, proposed by Burton Schuster, rests on the use of a saturable cell at the laser output. The highly absorbent cell is bleached by, and therefore made wholly transmitting to, the high-intensity laser pulse. The following fluorescence is not intense enough to bleach the cell, and hence is attenuated. An additional benefit is the sharpening of the laser pulse due to the attenuation of the low-level intensity in the pulse wings.

After considerable delay, the manufacturer made a minor modification to the laser head to accommodate the output cell. The system is now under study. Preliminary results indicate the possibility of reducing fluorescence intensity by 75%, without reducing laser pulse intensity by more than 10%. Several other improvements have been incorporated in the receiving system in an effort to increase the signal-to-noise ratio. We hope to resume our atmospheric probing experiments soon, with the revised laser system.

Our attempt to analyze data from the Sacramento Peak observations revealed another major problem. To permit the use of the high repetition rate of the laser system, a more sophisticated presentation than an oscilloscope provides is necessary. Consequently, Schuster, in cooperation with Robert Watson and representatives from the electronic industry, has determined the specifications for a fully automatic data-gathering and analysis system. The details of the system are currently under study.

In the laboratory, Watson studied the polarization of scattered helium-neon laser radiation (6328A) as a means of detecting the phase change from supercooled liquid water droplets to ice crystals. A supercooled cloud is generated in a small cloud chamber and the scattering intensity, at a given polarization angle, is measured at 90°. The cloud is then seeded with dry ice and the changes in scattering intensity observed. Preliminary analyses of the data show an observable change. However, quantitative results will require a spectrum analysis of the intensity versus time of the raw data.

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ATMOSPHERIC SIMULATION (ASP-LAS PROJECT)

In attempting to unravel the mysteries of the atmosphere, scientists often have dreamed of solving some problems through the use of devices to simulate atmospheric processes. These dreams have reached rather extravagant proportions at times, both in physical dimensions and in consequent costs. One of the proposed projects that has generated a considerable amount of discussion in terms of possible interest for NCAR is the concept of a large laboratory for atmospheric simulation. Unfortunately, the views on the "ideal" simulation facility are nearly as diverse as the number of atmospheric processes one can study in the laboratory. To try to determine the possibilities for and equipment requirements of major projects in atmospheric simulation, George Hidy was asked in 1965 by the directors of NCAR to organize a year-long colloquium on this subject.

After nearly two years, the colloquium -- or running debate -- on simulation has terminated, and the opinions and proposals of many scientists in NCAR and in the outside scientific community have been assimilated. The survey has included many simulation experiments bearing on a variety of atmospheric phenomena, these phenomena ranging in scale from molecular or near-molecular processes to planetary-scale atmospheric motion (Hidy, in press). Past efforts in the field of simulation, as well as future prospects, were examined. It was concluded that no large simulation facility could be built which would provide for the needs of all classes of future experiments. However, several special projects requiring major expenditures in effort and equipment appeared to be worth undertaking as part of expanded "national" programs in simulation. These projects and the results of the survey are discussed in detail by Hidy in an NCAR Technical Note (1966).

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LABORATORY OF ATMOSPHERIC SCIENCES PERSONNEL, 1966

DIRECTOR

William W. Kellogg

ASSISTANT TO THE DIRECTOR

William L. Jones

SCIENTISTS

Eric R. Allen
William R. Atkinson
Arnold E. Bainbridge (to 1 July 1966)
David P. Baumhefner (from 1 December 1966)
Edward R. Benton (leave of absence from September 1965)
Irving H. Blifford, Jr.
John A. Brown, Jr.
Robert H. Bushnell
Richard D. Cadle
Jitendra V. Dave
James W. Deardorff (leave of absence from 15 September 1966)
William H. Fischer
Alexander Goetz
Guy G. Goyer
George M. Hidy
David D. Houghton
Walter L. Jones
Paul R. Julian
Akira Kasahara
Charles A. Knight

Gerhard Langer
Donald H. Lenschow
Douglas K. Lilly
Richard S. Lindzen (from 2 March 1966)
James P. Lodge, Jr.
Edward A. Martell
John E. Masterson (from 31 January 1966)
Carlton L. Mateer (from 14 April 1966)
Chester W. Newton
Farn P. Parungo
John B. Pate
John M. Pierrard (to 19 September 1966)
Myron N. Plooster
Stewart E. Poet (from 8 November 1966)
Jan Rosinski
J. Doyne Sartor
Keith Schofield
Burton G. Schuster (from 25 January 1966)
Julian P. Shedlovsky
Patrick Squires (to 30 November 1966)
Henry M. E. van de Boogaard
Harry van Loon
Warren M. Washington
Edward J. Zipser (from 29 April 1966)

ASSISTANT SCIENTISTS

Evan L. Ausman, Jr. (from 1 September 1966)
Kent W. Bagley
Humberto Bravo A. (leave of absence from 1 August 1965)
Paul M. Brown
Marion B. Emmanuel
Paul M. Furukawa
Sonia N. Gitlin
Vincent M. Glover
Philip L. Haagenson
Miles LaHue
Allen L. Lazrus
Alan H. Miller (to 15 February 1966)
Clarence T. Nagamoto
Mark E. Ryan (to 30 December 1966)
David C. Sheesley
Claire E. Shelden, Jr.
Gladys E. Sturdy
Arthur F. Wartburg
Charles A. Watkins (to 1 November 1966)
Robert D. Watson
Glen E. Willis

ENGINEERS

Raymond D. Chu
Edward H. Denton
Walter C. Glaser

VISITING SCIENTISTS
(long-term)

Tomio Asai (Meteorological Research Institute, Tokyo; from 1 October 1964 to 1 October 1966)
Roy K. Berggren (Swedish Meteorological & Hydrological Institute, Stockholm; from 1 June 1966 to 7 October 1966)
Theodore W. Cannon (Oregon State University, Corvallis; from 19 September 1966 to 19 September 1968)
Dieter Ehhalt (University of Heidelberg; from 1 September 1964 to 1 September 1966; extended to 25 August 1967; transferred from ASP 1 September 1965)
Desiraju B. Rao (University of Chicago; from 1 November 1965 to 7 January 1967; transferred from ASP 1 November 1966)
Peter M. Saunders (Woods Hole Oceanographic Institution, Mass.; from 12 September 1966 to 12 September 1967)
Bengt Söderberg (Royal Swedish Air Force, Barkaby, Sweden; from 1 September 1964 to 28 February 1966)
Kvetoslav Spurny (Czechoslovak Academy of Sciences, Prague; from 1 September 1966 to 1 September 1967)
Johannes J. Taljaard (Weather Bureau, Pretoria, South Africa; from 12 September 1966 to 12 September 1967)
Ignaz Vergeiner (St. Justine, Austria; from 1 September 1966 to 1 September 1967)
William P. Winn (University of California, Berkeley; from 19 July 1966 to 19 July 1968)
Kwang-Sik Yun (National Research Council of Canada, Ontario; from 27 December 1965 to 27 December 1967)

VISITING SCIENTISTS
(short-term)

Bernice Ackerman (University of Chicago; from 1 July 1966 to 15 August 1966)

Fred C. Bates (St. Louis University; from 8 June 1966 to 8 September 1966)

John DeLuisi (Florida State University, Tallahassee; from 28 June 1966 to 28 October 1966)

Hans U. Dütsch (Laboratory for Atmospheric Physics, Zurich; from 22 August 1966 to 3 September 1966)

Lester F. Hubert (National Environmental Satellite Center, Washington, D. C.; from 8 August 1966 to 19 August 1966)

Donald R. Johnson (University of Wisconsin; from 6 July 1966 to 6 August 1966)

Morris Neiburger (University of California, Los Angeles; from 1 August 1966 to 12 August 1966)

David R. Rodenhuis (University of Washington, Seattle; from 15 June 1966 to 1 September 1966)

James C. Sadler (University of Hawaii, Honolulu; from 6 June 1966 to 1 September 1966)

Aylmer Thompson (Texas A & M Univ., College Station; from 1 June 1966 to 1 September 1966)

James W. Telford (CSIRO, Sydney, Australia; from 15 July 1966 to 10 September 1966)

VISITING STUDENTS

Jeffrey C. Bauer (University of Colorado; from 23 May 1966 to 19 August 1966)

Gregory Bullen (University of Colorado; from 7 June 1966 to 19 August 1966)

J. Graham Bunting (Hartley Victoria College, Manchester, England; from 13 July 1966 to 23 September 1966)

Jeremy Howell (Parsons College, Fairfield, Iowa; from 8 June 1966 to 19 August 1966)

Jean Pwu (Winnipeg, Manitoba, Canada; from 9 May 1966 to 22 August 1966)

Roger Shreck (Kansas State Teachers College; from 6 June 1966 to 1 September 1966)

William J. Taffe (University of Chicago; from 20 June 1966 to 9 September 1966)

David L. Williamson (MIT, Cambridge, Mass.; from 13 June 1966 to 26 August 1966)

Janet M. Wood (University of Colorado; from 10 May 1966 to 12 September 1966)

RESEARCH ASSISTANTS AND TECHNICIANS

Charles E. Abbott

Blair E. Ammons (to 26 August 1966)

Lawrence R. Baker (from 6 September 1966)

William D. Booton

Charles C. Catlin (transferred to FAL 17 December 1966)

Ralph L. Coleman

Gary B. Corless (to 21 October 1966)

Karl Danninger (from 21 November 1966)

Gerald J. Dolan

Paul A. Eden

Evelyn R. Frank

Charles L. Frush (from 28 March 1966)

Charles H. Garhart

Adrian D. Gibson

Frank E. Grahek

Ada Greenwood (from 28 July 1966)

Walter Grotewold

Leroy E. W. Heidt

G. Dale Hess (from 13 June 1966)

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Nancy Knight

Ronald J. Kovac (from 18 April 1966)

Stephen W. Kovacs

Juey-Rong Lai

Linda A. Leiker

San San Lin

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Richard A. Lueb

Lawrence J. McElhaney

Benny E. Nasser, Jr. (to 25 February 1966)

Ilga R. Paluch

Walter H. Pollock

R. Ann Pugh (to 11 November 1966)

Lynn D. Ringer (from 23 February 1966)

James E. Robin, Jr.

Mary Jo Scharberg

Nancy M. Seiller

Jean F. Smith (to 31 January 1966)

Dennis L. Tussy

Kathleen C. Underwood (to 31 May 1966)

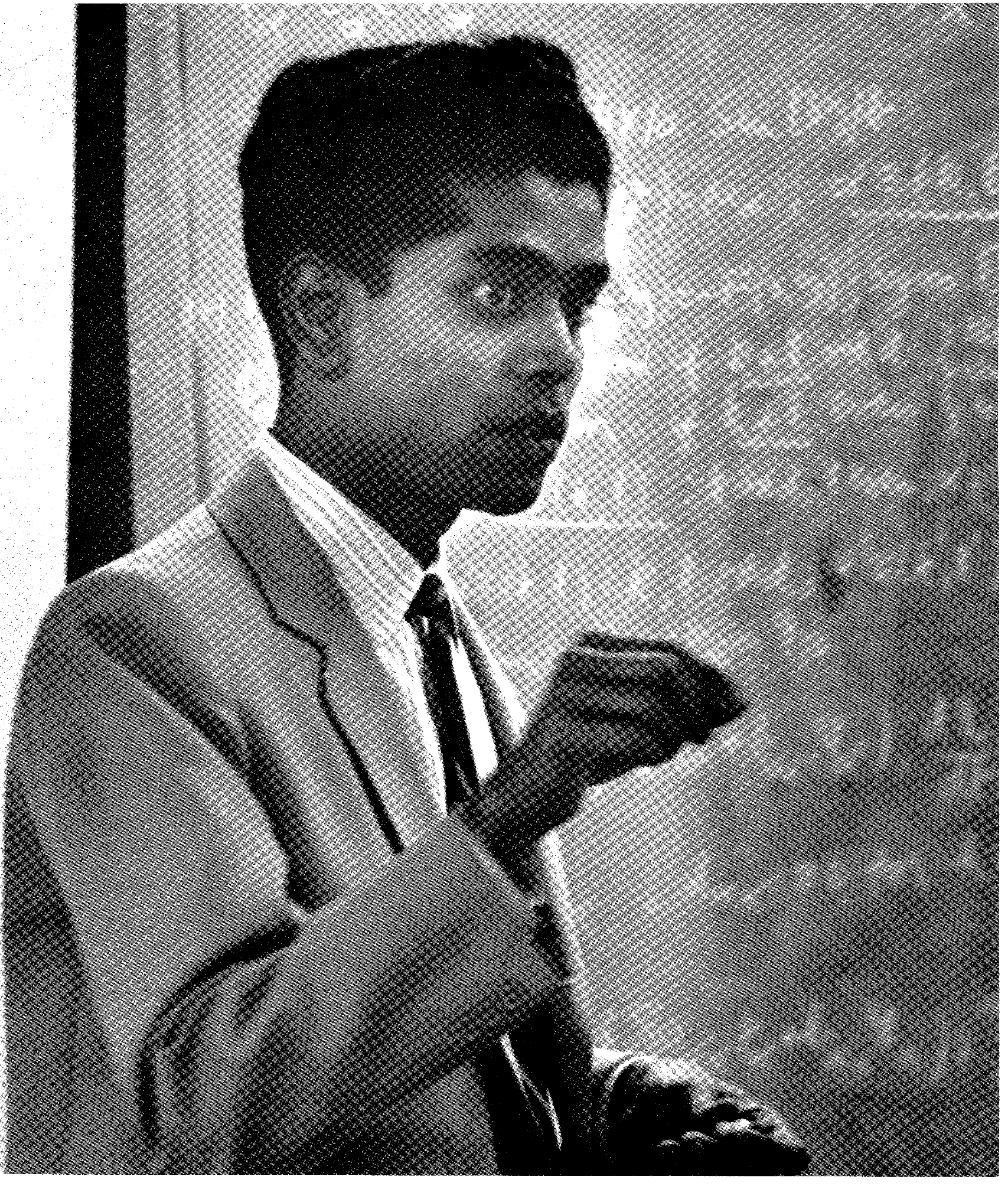
James R. Weber

Janet M. Wood (from September 1966)

OFFICE STAFF

Betty L. Bennett (transferred from Adm. 12 December 1966)
Betty Davie (transferred from Adm. 10 January 1966)
Mary C. Gordon (to 31 August 1966)
Kathleen L. Hatt
Barbara L. Hill (transferred from HAO 26 September 1966)
Margaret Johnstone
Christine Kobl (to 11 March 1966)
Gayle F. Lowndes
Cynthia S. McClendon (from 26 September 1966)
Diane G. Merrill (from 5 October 1966)
Maxine F. Ross
Linda G. Sahm
Anne T. Scott (transferred to Adm. 1 September 1966)
Jane C. Stroh (to 14 October 1966)
Joyce L. Teter (to 23 December 1966)
Carol S. Tillman (to 5 January 1966)
Lois A. van Dusen

Advanced Studies Program



INTRODUCTION

As in the previous two years of its existence, the Advanced Study Program (ASP) has consisted primarily of two activities: the support of postdoctoral appointees on one-year research appointments, and visits of senior scientists to NCAR and support of their research while here. A new type of enterprise in 1966 was the organization of an eight-week summer colloquium.

POSTDOCTORAL APPOINTMENTS

Postdoctoral appointments are usually given to people who have only recently completed their doctors' degrees, and who may be only recently or very slightly acquainted with the atmospheric sciences; their backgrounds in mathematics, physics, and chemistry must be broad enough that the transition from one field to another can be made without further basic education. Some appointments, however, go to people whose degrees lie five to ten years behind them. Teaching duties may have limited their time for original research, and we feel they might profit from intensive exposure to a new and challenging field. With regard to the latter group, we are particularly anxious to attract teaching faculty members of undergraduate colleges, as their student bodies are not easily accessible except through direct contact with their own professors.

Each participant is normally expected to seek a position in a university or some other research organization after a year of study and research, except when his value would be very considerably enhanced by a second year with ASP. It is neither planned nor expected that any significant number of participants in ASP will remain as permanent members of NCAR.

SEMINARS AND LECTURES

In regularly scheduled seminars and short, irregular series of lectures, members of the Advanced Study Program are brought into contact with a broad range of problems in atmospheric dynamics, atmospheric physics, and atmospheric chemistry, with special emphasis on the body of theory that is common to many fields. These seminars and lectures are generally conducted by the permanent and visiting staff of ASP, but some, particularly those dealing with experimental problems, are given by members of the Laboratory of Atmospheric Sciences or the High Altitude Observatory.

Permanent senior staff members of ASP conducted two series of seminars during 1966.

- The Winter/Spring Seminar, directed by Philip Thompson and Walter Jones, had as its subject the structure of turbulent Couette flow.

- The Fall/Winter Seminar, led by Sydney Chapman, reviewed geomagnetic daily variations and airflow in the ionosphere, and was held in conjunction with the Department of Astro-Geophysics of the University of Colorado.

COLLOQUIUM ON THERMAL CONVECTION

During the summer we organized a colloquium on thermal convection. This was our first summer colloquium, and with it the entire emphasis of summer invitations was changed. Formerly the majority of summer visitors were senior scientists from many fields. This year we invited more graduate students and fewer senior scientists, with the latter being asked specifically because of their ability to lecture on thermal convection. The colloquium provided far more direction for graduate students than was formerly possible; each student chose or was assigned a problem and a senior visitor with whom he could discuss the problem. Each student was also responsible for writing up notes on two lectures. These notes were compiled into the Proceedings of the colloquium, which will appear early in 1967 as NCAR Technical Note 24.

We feel that the first summer colloquium was definitely a success, and plan to hold a second colloquium in the summer of 1967. The subject will be coronal physics.

PARTICIPANTS IN THE COLLOQUIUM

Lecturers

Tomio Asai, NCAR
Albert Barcilon, Harvard University
James W. Deardorff, NCAR
Mariano A. Estoque, University of Hawaii
Raymond Hide, Massachusetts Institute of Technology
Lester F. Hubert, U. S. Weather Bureau, Suitland, Maryland
Akira Kasahara, NCAR
Douglas K. Lilly, NCAR
Richard S. Lindzen, NCAR
Bruce R. Morton, University of Manchester, England
Chester W. Newton, NCAR
Harold D. Orville, South Dakota School of Mines and Technology
Norman A. Phillips, Massachusetts Institute of Technology
George W. Platzman, University of Chicago
Patrick Squires, NCAR
Philip D. Thompson, NCAR
Warren M. Washington, NCAR

UCAR Fellows

William R. Barchet, Drexel Institute of Technology
A. A. Kennel, DePauw University
James Mitchell, University of Indiana

Summer Visitors

Kenneth C. Brundidge, Texas A & M University
T. W. Hildebrandt, Ohio State University
Richard H. Jones, Johns Hopkins University
Conway Leovy, The RAND Corporation

Students

Dennis G. Baker, Massachusetts Institute of Technology
John R. Bates, Massachusetts Institute of Technology
Alfred S. Carasso, University of Wisconsin
Sou-Hsiung Chiu, New York University
G. Brant Foote, University of Arizona
Kenneth S. Gage, University of Chicago
Man-Kin Mak, Massachusetts Institute of Technology
Ronald D. McPherson, University of Texas
R. W. Miksad, Massachusetts Institute of Technology
Gary Parker, Cornell University
David R. Rodenhuis, University of Washington
Melvyn A. Shapiro, Florida State University
William L. Siegmann, Massachusetts Institute of Technology
Peter J. Webster, Florida State University

RESEARCH

All members of the Advanced Study Program are encouraged to pursue research of their own, either alone or in collaboration with members of the NCAR permanent staff. Some of the research projects conducted by the permanent staff and postdoctoral appointees are described below.

- Bernhard Haurwitz continued his studies of the lunar barometric tide and analyzed data from fourteen additional stations. Together with Benson Fogle of the Geophysical Institute of the University of Alaska, he prepared an extended review of noctilucent clouds. During the spring quarter Haurwitz gave a series of lectures on geophysical hydrodynamics at Colorado State University. In the fall quarter he visited the University of Texas, where he is an affiliate professor, and presented lectures on atmospheric wave motions. Haurwitz will assume the directorship of ASP in 1967.

- Sydney Chapman continued his studies of the large-scale thermal and tidal daily oscillations of the atmosphere, studying specifically the relation of pressure at Copenhagen to the solar and lunar daily variations. He also collaborated with S.-I. Akasofu and C.-I. Meng of the University of Alaska in studying the polar electric current systems associated with magnetic disturbances and auroral phenomena. The auroral electrojet current flows along a curve which these authors call the auroral oval, and which differs from the auroral zone, a statistical conception especially related to the changing location of the most intense part of the electrojet throughout each 24 hours. With Peter Kendall, Chapman continued studies of the field of a symmetrical ring current in the magnetosphere, using the method of Legendre functions to obtain estimates of the field energy changes during a magnetic storm; these were similar to those he had obtained earlier on the basis of simpler models. Chapman also studied the solar and lunar daily magnetic variations at San Fernando, Spain, and their day-to-day variability there. The computed results are not yet interpreted.

- Philip Thompson has completed work on two distinct theoretical approaches to turbulent shear flow. One of these yields the gross statistical characteristics of the flow, and the second provides the structure of the boundary layer and its dependence on Reynolds number. A third approach, not yet completely explored, is fundamental in that it is ostensibly capable of determining the numerical value of von Kármán's constant, in addition to determining the statistical structure of turbulent Couette flow.

- Rumen Bojkov from the University of Sofia, Bulgaria, began an analysis of atmospheric ozone distribution and variations on the ground of all known total and vertical ozone observations. He hopes to develop a numerical experiment for realistic accounting of the role of ultraviolet and 9.6 μ-band radiation absorbed by ozone, as an energy source in the dynamics of large-scale circulation.

- Reiner Gebhart, who is on leave from the Technische Hochschule in Munich, Germany, spent 1966 working on atmospheric radiation and photochemistry. He completed papers on the significance of shortwave CO_2 absorption in investigations concerning the CO_2 theory of climatic change, and is preparing a paper on photochemical, advective, and turbulent effects on the meridional ozone distribution, a study of the time-dependent problem.

- Arne Grammeltvedt, from the University of Oslo, Norway, is working on computational instability and truncation errors of finite difference schemes used in long-term integrations.

- Joachim Joseph, from UCLA, completed his research on diurnal and solar variations of neutral hydrogen in the thermosphere, and also worked on the detection of noctilucent clouds. He is currently working on the influence of atmospheric aerosols on radiation flux in the infrared.

• Bruce Morton, from the University of Manchester, England, completed research on the dynamics of convection in the atmosphere, related to the dynamical modeling of cumulus clouds. He also worked on source and sink flows in stratified fluids.

• James O'Brien came to ASP after completion of his doctoral degree at Texas A & M University. During 1966 he continued work on air-ocean interactions and hurricanes.

• Dennis Parkyn, who is on leave from the Department of Applied Mathematics, University of Cape Town, South Africa, has been working on analysis of oscillatory perturbations in satellite drag data in order to determine the response structure of the high atmosphere.

• Arthur Pike, from Cambridge University, England, continued work on atmospheric boundary-layer problems and atmospheric turbulence. He is now teaching meteorology at the University of California at Los Angeles.

• Ralph Smith, on leave from the Department of Mathematics, Keele University, England, completed a study of the boundary layer beneath intense vortices such as tornadoes. This research will appear soon as an NCAR prepublication review. He is now working on a numerical study of a tropical cyclone.

• Richard Somerville, from New York University, is developing theoretical models for boundary-layer phenomena in laboratory-scale flows subject to rotation and differential heating.

COLLOQUIUM ON ATMOSPHERIC SIMULATION

ASP was asked in 1965 by the directors of NCAR to organize a colloquium on atmospheric simulation, with the specific objective of determining feasibility of projects in this field.

Late in 1966, after nearly two years' effort, discussions of the colloquium are ended, and the opinions and proposals of many scientists in NCAR and in the outside scientific community have been assimilated. The survey included many simulation experiments bearing on atmospheric motion phenomena ranging in scale from molecular or near molecular to planetary.

It was generally concluded that no simulation facility could be built to provide for the needs of all classes of future experiments. However, several special projects requiring major expenditures in effort and equipment appear to be worth undertaking as part of an expanded "national" program in simulation. These projects and the results of the survey are discussed in detail in a report by George Hidy (1966), the organizer of the colloquium.

ADVANCED STUDY PROGRAM PERSONNEL, 1966

DIRECTOR

Philip D. Thompson

PROFESSIONAL

Bernhard Haurwitz
Sydney Chapman

SUPPORT

Ann E. Day
Ann D. Cowley

POSTDOCTORAL APPOINTEES, 1966-1967

William Blumen (to June)
Rumen D. Bojkov (from December)
Reiner Gebhart (from April)
Aldo Giorgini (from June)
Jagdish Gupta (from December)
Joachim H. Joseph (from August)
James J. O'Brien (from February)
Dennis G. Parkyn (from August)
Arthur Pike (from May)
D. B. Rao (from November)
Ralph Smith (from March)
Richard C. J. Somerville (from July)

LONG-TERM VISITORS

Abdul Abdullah (to October)
Dusan Djuric (to September)
Arne Grammeltvedt (from August)
Bruce Morton (from August)
Norman Phillips (to September)
Michael Yanowitch (to September)

PUBLICATIONS OF THE ADVANCED STUDY PROGRAM, 1966

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Akasofu, S.-I., S. Chapman, and A. B. Meinel, 1966: "The aurora," Handbuch der Physik 49, 1-158.

______, ______, and C.-I. Cheng, 1966: "The polar electrojet," J. Atmos. Terrestr. Phys. 27, 1275-1305.

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______ and A. D. Christie, 1966: "Vertical ozone distribution over New Zealand," J. Atmos. Sci. 23, 791-798.

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______, 1966: "Magnetic and ionospheric storms," in Equatorial Aeronomy Sao' Jose' dos Campos, Nov. 1965, F. deMendonca, ed., 449-454.

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Grammeltvedt, A., 1966: "On the non-linear computational instability of one-dimensional flow," Geofysis. Publikasj., Oslo.

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Kendall, P. C., S. Chapman, S.-I. Akasofu and P. Swarztrauber, 1966: "The computation of the magnetic field of any axisymmetric current distribution with magnetospheric applications," Geophys. J. R. Astr. Soc. 11.

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Facilities Laboratory

INTRODUCTION

It has been recognized, since the early days of NCAR, that one of its principal responsibilities is to plan and execute basic atmospheric science research programs in collaboration with other scientific and educational institutions or organizations; such programs being characterized by the necessity for large-scale research operations involving observations and measurements made over wide geographic areas using a complex variety of vehicles, devices, instrumentations and techniques. The first example of such a program, the Line Islands Experiment (LIE), has occupied the full attention of major elements of the Facilities Laboratory (FAL) during the last quarter of this year.

This experiment was conceived and planned by a group of scientists from universities, NCAR, and government agencies. The Steering Committee of the LIE requested the FAL to serve as manager of operations and logistics for the field phase. William Lanterman, Manager of the Field Observing Facility, is manager of the operational support program.

Late in 1966, a survey trip was made to the Line Islands to facilitate detailed planning. Observing elements will be in the field and operational by mid-February 1967.

As one looks to the future, it is easy to see that the Line Islands Experiment may turn out to be only the first of a series of large-scale field experiments in which the Facilities Laboratory plays a leading role in field planning and management.

During 1966, the Facilities Laboratory continued to operate three joint-use facilities serving both NCAR and the university community of atmospheric scientists: the NCAR Scientific Balloon Facility, established in 1961; the NCAR Research Aviation Facility, established in March 1964; and the NCAR Computing Facility, transferred from the Laboratory of Atmospheric Sciences to the Facilities Laboratory in July 1964. The Field Observing Facility also became a joint-use Facility, available to non-NCAR scientists, in January 1966. Late in 1966, the Global Atmospheric Measurement Project was formed as a formal unit, split off from the Balloon Facility. In another internal reorganization, the NCAR Library and the Electronics Shop were transferred to Administrative and Support Services in February 1966.

The NCAR Shop was redesignated the Design and Prototype Development Facility, with an increased mechanical and electronic design capability. This Facility is expected to serve as a focal point for engineering design within NCAR.

A final note of general interest was the success of two student summer work programs. The first of these, an introduction to the use of aircraft as research platforms, was conducted by the Research Aviation Facility. The second was a work-study program to familiarize students with the uses of large electronic computers. Both programs were favorably received and will be repeated in 1967.

Daniel F. Rex
Director

SCIENTIFIC BALLOON FACILITY

OPERATIONS

The Balloon Facility operated from its Palestine, Texas launch station throughout 1966, and also conducted flights from 23 January to 25 February from the Naval Air Facility at Litchfield Park, Arizona. (Litchfield Park was used instead of Page, Arizona for these flights because adequate facilities were not yet developed at Page.)

An expedition to South America cooperating with the High Altitude Observatory, the Naval Ordnance Test Station, and the University of Colorado, sought to launch balloon-borne equipment to observe ozone in the path of the 12 November eclipse. Strong winds at the scheduled launch time prevented a successful launch on the first attempt, and there was insufficient time to make a second attempt.

A program of long-duration superpressure balloon flights (GHOST) was carried out from New Zealand through almost the entire calendar year. This program was the first full-scale field test of the GHOST concept; a more detailed discussion is given below.

Balloon performance during the year has been generally good. Balloon bursts during ascent have been reduced from approximately 25% when NCAR first began balloon operations to approximately 4% during 1966. Better balloon performance seemed to increase the opportunity for other operational difficulties, and launch failures and electronics failures were more numerous during 1966 than they had been the previous year. A new crew and aging electronics equipment undoubtedly contributed to this deterioration. The overall operational record for 1966 is the best thus far for NCAR, however.

RESEARCH AND DEVELOPMENT

We have continued our efforts to design and develop better balloons, emphasizing the development and use of better materials, improved electronics, and improved operational equipment and techniques.

We have calculated new designs for balloons, which depart from recent balloon design practice in that they deliberately incorporate horizontal circumferential stress. We believe that present methods of sealing balloon seams permit some such stress and that incorporating this stress may give certain advantages. Additional study of several possible circumferential stress distributions will be necessary before we feel we are prepared to fabricate and fly a balloon having such stresses.

We have flight-tested top-reinforced balloons; the only successful type so far has been the fully tailored, natural-shape balloon with a cap made of the same material as the balloon. We are planning and testing other shapes, involving such features as small cones or domes on top of the balloons to assist in deployment of material during ascent.

We have sponsored the development of a new manufacturing and repair tape which has good characteristics under extreme cold conditions. This tape was developed by Minnesota Mining and Manufacturing Co.; a report of its development (Zwack and Brown, 1966) and samples of the tape were forwarded to manufacturers and other interested groups.

Electronics and pressure-sensing equipment of the same basic types as those already in operational use have been purchased to replace aging airborne equipment. The new equipment gives somewhat refined pressure measurements at high altitudes, but still is not completely adequate for the high-altitude flights now being made. We have searched extensively for pressure-sensing equipment for the higher altitudes, and for a very lightweight sensor which could be used with the GHOST system. Neither search has yielded a completely satisfactory sensor.

Additional FM/FM channels have been added to the NCAR operational telemetry equipment, and a new command system is under development and nearing the operational stage.

Two systems for launching heavy, delicate payloads were developed and tested during the year. One of these is similar to a system used by the U. S. Air Force Balloon Facility, the other is new. Both permit re-alignment of the balloon train after inflation is completed. We used one system successfully in launching the engineering version of the Fraunhofer Institute telescope; the other, called "Stonehenge" because it has a circular array of anchors, was used to launch medium-weight experimental payloads. It will be tested soon with a very heavy load. In both of these techniques, accelerations at launch have been kept very low.

Bids were requested in August for construction of a "Clamshelter" inflation shelter at Palestine. Since the lowest bid was well above available funding, the proposal has been abandoned.

MAJOR BALLOON PROGRAMS

GHOST Program

The GHOST Flight Program was started in February in New Zealand. Small superpressure balloons, each carrying a very lightweight electronics package, have been flying quite successfully in the southern hemisphere. Several of these balloons have flown at 200 mb for periods of several months -- one has flown for more than six months and has made more than 16 complete circuits at southern latitudes. Several have been flown at 500 mb, but their periods of flight have not exceeded a few weeks; we believe that they were brought down by icing. Our 30-mb balloons (which are much larger) have also been launched successfully but have not been flying long enough to allow estimates of their flight duration; however, in theory they could fly for years.

Data from this program have been unexpectedly good, and the GHOST balloons promise to make a great contribution to our understanding of the general circulation of the southern hemisphere.

Polariscope

One attempt to fly Polariscope, a balloon-borne telescope designed and built by the University of Arizona, ended in failure when the balloon, launched from Litchfield Park, Arizona, burst during ascent. A second attempt, made from Palestine in May, resulted in an unusually successful flight: all the experimental equipment operated as expected and the telescope received very little injury on landing. Additional flights of Polariscope are planned for 1967.

Spectro-Stratoscope

An engineering version of a telescope designed by the Fraunhofer Institute, Germany, was flown in November. This flight also appears to have been unusually successful: everything functioned as planned and the scientific group obtained abundant engineering data for use in designing a balloon-borne solar telescope, which is scheduled for completion in 1967.

University of California Space Sciences Laboratory Experiment

The first engineering flight of a high-energy physics experiment being prepared by a group under Dr. Luis Alvarez of the University of California was flown from Palestine in July. This flight apparently provided all the engineering data which the scientific group had hoped for. It also provided the group with their first experience in balloon-borne experimentation. They will conduct their own flights in the future, using a contract crew. They expect to fly from a California site and recover at sea.

GAMP

Late in 1966 the Global Atmospheric Measurement Project (GAMP) was formed as a split-off from the Scientific Balloon Facility.

The mission of GAMP is to develop new techniques and instruments for obtaining atmospheric measurements. The GHOST development program will continue under GAMP. Two new instrument packages are being designed and tested: MOSES (Meteorological Observing Station, Extremely Simple), for observations on remote islands, deserts, and mountains; and Minisonde, a lightweight balloon-borne radiosonde package designed to be of no danger to aircraft.

COMPUTING FACILITY

INTRODUCTION

The primary mission of the NCAR Computing Facility is to provide computing capacity for all phases of meteorological research. A computer large and fast enough to solve all the important meteorological problems which could be formulated today would stagger the imagination. The Computing Facility attempts to provide the best possible computing service consistent with its budget and computer and programmer availability, and to develop new computing techniques or improve existing techniques when the need arises.

Unlike most similar organizations throughout the country, the NCAR Computing Facility is funded for total operation. The NCAR Directors are kept informed of the usage of the machines, and larger users are advised of the machine time they use each month. Scientists are not required to fund in their individual projects for computing.

Programmers are hired by the Computing Facility and assigned to individual scientists, allowing us to maintain a consistently high level of accomplishment among the programmers and to adjust the programmers' work loads so that they are always busy but never swamped.

This has been a rather chaotic, trying year. The Control Data Corporation 6600 arrived on 6 January. The Control Data 3600 had already been moved to the Martin Company, in Littleton, for our use. For the next three months most of our actual production was run on the 3600. The 6600 gradually began to function and finally, on 14 May, it was accepted. Individual projects were moved one at a time from the 3600 to the 6600, until in April we relinquished the 3600. The 6600 ran well and our work load grew. Our move to the new NCAR Laboratory during December necessitated a three-week shut-down.

USE

During 1966, use of the NCAR computer increased greatly and turnaround time greatly decreased. The multiprogram system with direct card input has made possible five-minute turnaround on small jobs, permitting many runs per day. Since debug time is more a function of the number of test runs than of calendar time, quick turnaround has increased significantly the amount of useful work a scientist can accomplish.

The increased speed potential has made us speed up our scheduling procedures almost to the point of eliminating them. A growing number of keypunch machines will also increase our speed.

In 1966, forty-three scientists used the Computing Facility for the first time. Twelve of these were non-NCAR users. Non-NCAR use increased substantially in 1966, even though the number of computer hours decreased. There were 36 non-NCAR projects on the computer, as compared to 21 in 1965. We expect non-NCAR use to increase further in 1967. The use of the machine is best shown in Figs. 1 through 7.

We are no longer accepting jobs outside the atmospheric sciences, as the machine is now working to capacity on atmospheric research.

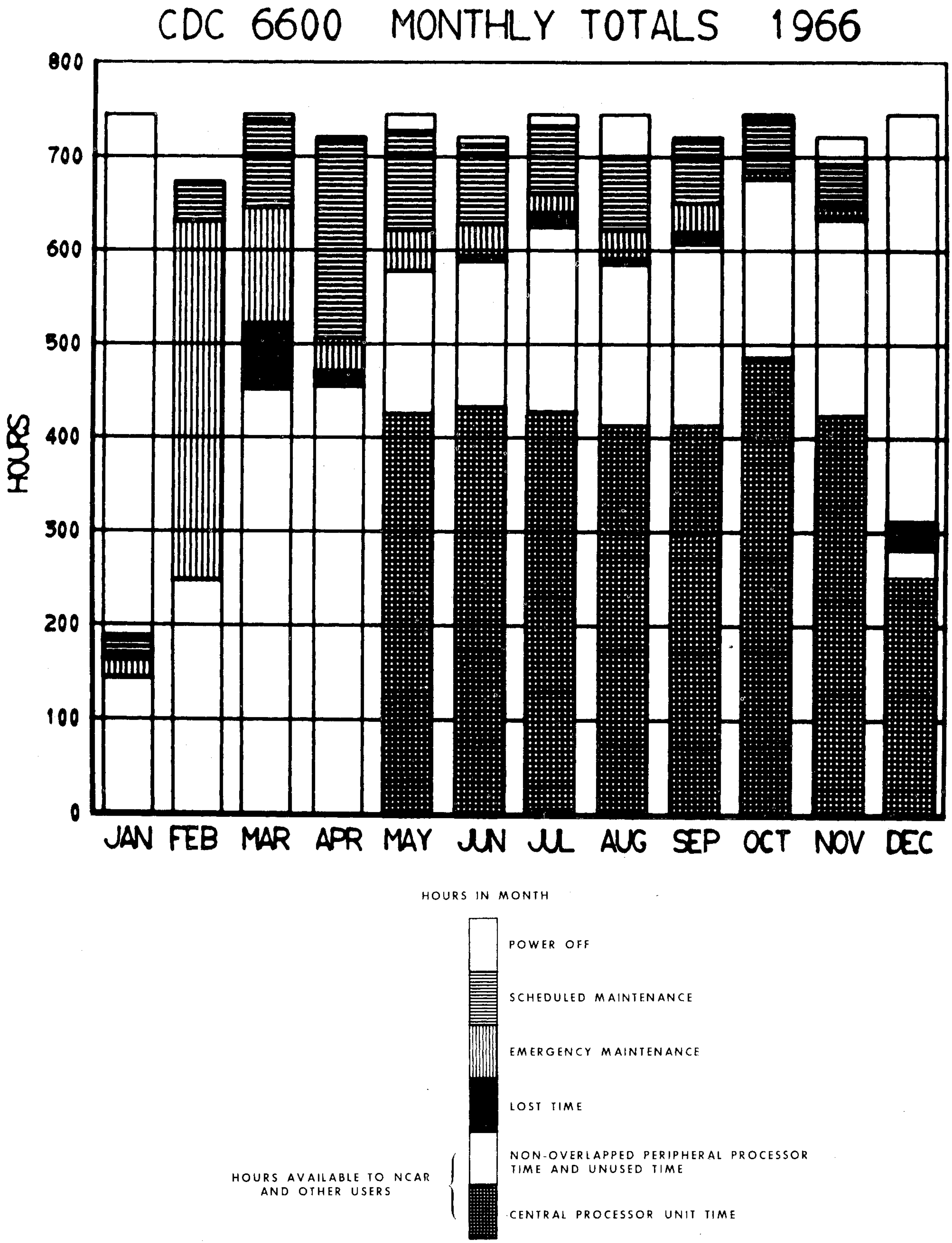

Fig. 1 Computer use during 1966 (monthly totals).

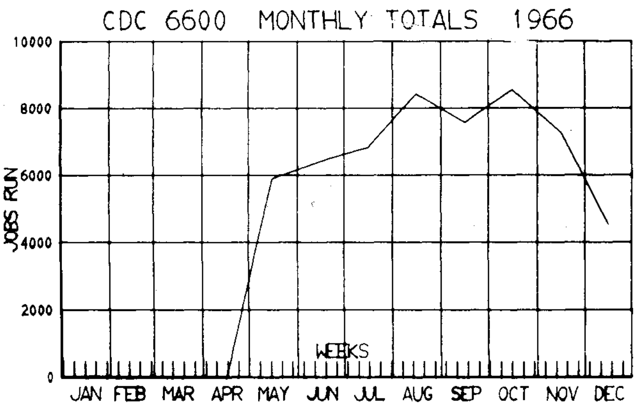

Fig. 2 Jobs run during 1966 (monthly totals).

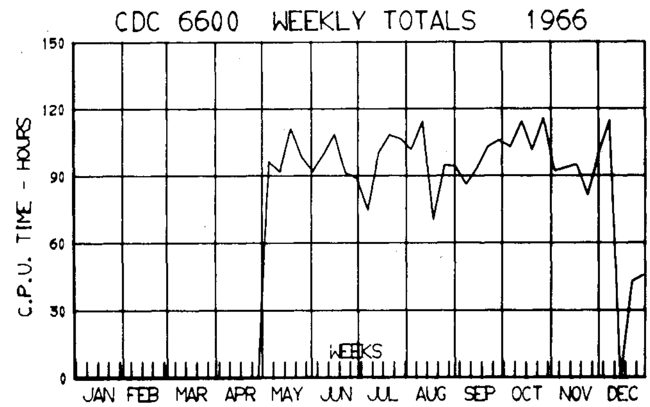

Fig. 5 Jobs run during 1966 (weekly totals).

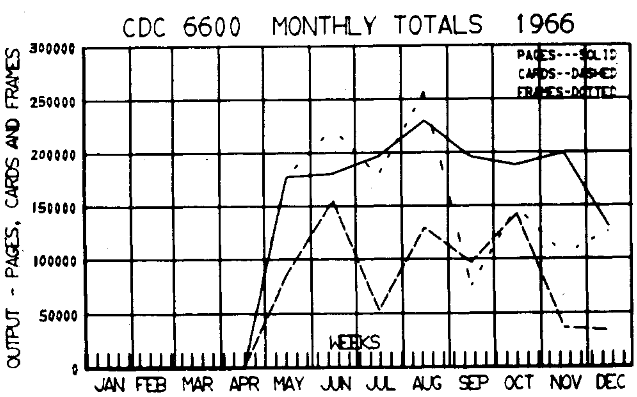

Fig. 3 Output during 1966 (monthly totals).

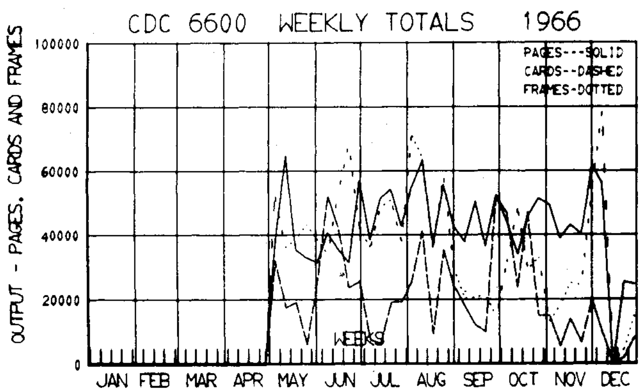

Fig. 6 Output during 1966 (weekly totals).

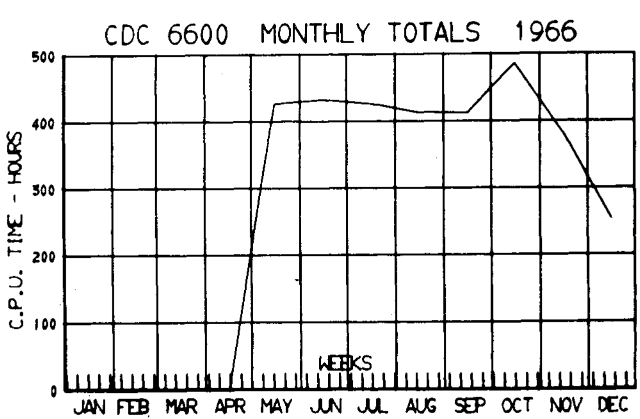

Fig. 4 C.P.U. time during 1966 (monthly totals, in hours).

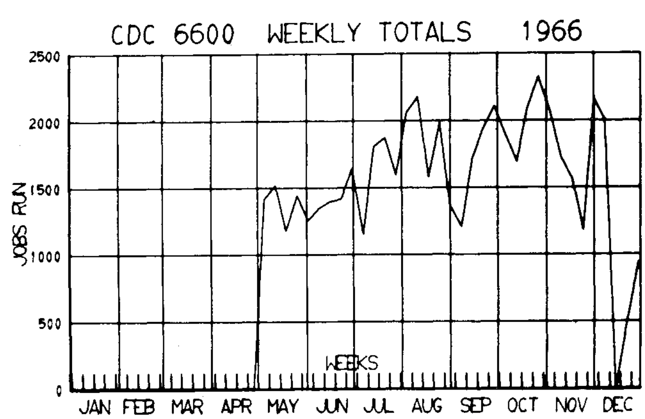

Fig. 7 C.P.U. time during 1966 (weekly totals, in hours).

ADVISORY PANEL

The Computing Facility Advisory Panel met on 27 October 1966, and adopted a policy to govern use of the computer. Policy highlights are as follows:

- It is assumed that the Computing Facility is saturated by programs directly related to the atmospheric sciences and that no free time exists. Since it is unlikely that free time will become available, this policy does not attempt to govern the distribution of free time.

- Any regularly employed NCAR staff member may place any scientific problem on the computer. All NCAR projects will be given equal priority.

- Any project which is a joint venture between NCAR and another organization (possibly even commercial) may be run on the computer.

- If an NCAR scientist feels that work being carried on by some non-NCAR scientist is of direct interest or use to his own program, then that work may be run on the computer. If and when the project exceeds ten hours, it must be reviewed by the Computing Facility Advisory Panel. The measure of interest should be the NCAR scientist's willingness or desire to carry out the computation if he had enough time and assistance to do so.

The Directors of NCAR have agreed to set aside computer time for non-NCAR scientists. All non-NCAR projects have equal priority and there should be no conflict, since new projects will not be accepted until there is time in the non-NCAR category.

CURRENT PROJECTS

Summer Training Program

One of NCAR's stated goals is "to be responsive to needs expressed by the university community in the development of expanded and strengthened programs of education and research in the atmospheric sciences." During the summers of 1963, 1964, and 1965, the Computing Facility has worked toward this goal by training a few students in the uses of a large-scale computer. Jeanne Adams spent much of her time tutoring the students. In 1966 a formal work-study program for graduate students was established under her direction. Eight graduate students participated in the program:

Ernest Agee, University of Missouri
Fred Alyea, Colorado State University
William Barchet, Drexel Institute of Technology
Yeong-Jer Lin, New York University
Roy McCrory, New Mexico Institute of Mining and Technology
Daniel Rousseau, Massachusetts Institute of Technology
William Slusser, San Fernando Valley State College

With the increased number of students, the project was given more staff, computer time, and financial support, and the 1966 workshop was very successful. We are looking forward to working with a new group of young meteorologists in 1967.

New Data

We acquired several useful new sets of weather data during the year, including:

- Fourteen years of Pacific Ocean surface temperature analyses from the Bureau of Commercial Fisheries;

- A set of world upper-air climatological grids from the Air Weather Service;

- The second nine months of IGY grid analyses of the southern hemisphere;

- Nine more months of analyses from the National Meteorological Center;

- Vertical motion grids for the northern hemisphere, high-level analyses; and

- Additional high-level analyses.

Data-Handling Software

Under the direction of Roy Jenne, a large amount of data-handling software was written for the 6600. Since most of our data-handling programs were in 3600 machine language, they had to be completely redone for the 6600. The most important programs in this category are those that pack and unpack weather-record tapes.

In addition, programs were written to copy tapes, block and unblock tape data, sort data, and allow fast bit manipulation from Fortran programs.

Dennis Joseph is reformatting grid data from the National Meteorological Center and the U. S. Air Force into a single comprehensive format.

Other Data Projects

We have helped other groups with the checkout or design of data-gathering equipment: the Aircraft Facility in the checkout of their system for digitizing information gathered by aircraft; the Field Observing Facility in designing their analog-to-digital equipment; and the University of Texas in evaluating a "pencil follower" which could be used to digitize old weather maps or strip charts.

NCAR Computer Manual

Jeanne Adams, David Robertson, Paul Rotar, and Robert Working, with substantial help from others in the Computing Facility, compiled information relevant to use of the 6600 computer, and prepared a comprehensive manual for the NCAR Computing Facility. The first printing of one hundred copies is exhausted and a new, updated version is now in press.

THE FUTURE

The atmospheric sciences (and thus NCAR) have a large stake in the development of high-speed computers. We continue to encourage the development of "parallel" computers capable of solving three-dimensional hydrodynamics problems or general circulation problems 100 times faster than our present computer. As discussed in the 1965 Annual Report, we have been involved with IBM in studies of such computers (Kolsky, 1966).

We have also collaborated with Daniel Slotnick of the University of Illinois on the development of a network type of parallel computer, the Illiac IV. This computer will be composed of 256 arithmetic units, each with a "raw" speed somewhat greater than that of the 6600. The initial design phase for this machine is now complete; the contract for construction should be made early in 1967. The University of Illinois will test the utility of this machine for general circulation computations, and we intend to offer them all possible help.

If the Illiac IV meets its design goals, it will be a valuable new tool in general circulation computations and many other problems. Glenn Lewis and John Gary are working closely with the Illiac IV group and will help to select a finite difference scheme for this new machine.

RESEARCH AVIATION FACILITY

INTRODUCTION

During 1966, the NCAR Research Aviation Facility provided the atmospheric science community with a total of 1347 hours of airborne research time, and served 22 research programs, both in and out of NCAR. To satisfy rapidly increasing requests for flight support, we procured a third Beech Queen Air 80 in June 1966, and modified it to be compatible with existing research instrumentation systems.

We continued to test and evaluate state-parameter, cloud-particle, and liquid-water sensors. We acquired a doppler radar navigation system, including an airborne wind computer, and tested and evaluated it. We also evaluated the research potential of a Ku-band airborne weather avoidance radar.

We improved our Airborne Research Instrumentation System (ARIS), extending its data-recording capabilities and flexibility. We designed and acquired a portable ground playback system also.

As part of its services function, the Facility established liaison with several foreign research groups, conducted a graduate summer training program, assisted various non-NCAR groups with instrumentation programs, sponsored seminars, and co-sponsored a national workshop and symposium on Atmospheric Research Aircraft.

Plans were initiated to enlarge and expand the scope of research within the Facility.

DEVELOPMENT

Aircraft

Although we could not acquire a light jet aircraft during 1966, we updated our 1965 jet aircraft feasibility study to allow for recent developments in the light jet aircraft industry.

Our 1965 choice -- the North American Sabreliner -- still seems to be the most desirable jet aircraft for research purposes. Increased engine thrust has improved operational performance of the Sabreliner; a stretched version with 38 additional inches of cabin length is available and would provide for greater instrumentation payload and flexibility. Additional windows make visual observations easier, and the manufacturer has engineered two additional research installations for the Sabreliner.

By early 1966 the delay in acquiring the jet, and increased demands for Facility services, made it necessary for us to acquire a third propeller aircraft, so we leased another Queen Air. It was delivered early in June and almost immediately was flown to South Dakota to participate in Project Hailswath.

Operations Base

In January 1966, we leased 5000 sq ft of hangar space and 1500 sq ft of shop, laboratory, and storage space at Jefferson County Airport, providing semi-permanent quarters for the Facility for the first time. The third Queen Air and growing operational and instrumentation requirements led us to lease an additional 800 sq ft of shop, laboratory, and storage space in November. Some space is still available for lease should further expansion be necessary.

Planning for permanent laboratory, shop, and hangar space on a five-acre site at Jefferson County Airport has continued, including preliminary site evaluation and building cost estimates.

Aircraft Instrumentation

We have continued the aircraft instrumentation program outlined in the 1965 Annual Report. In 1966 we supported 12 research programs which required additional special instrumentation and aircraft modification.

A Bendix RDR-100 Ku-band Weather Radar was consigned to the Facility for evaluation, testing, and use during Fred Bates' thunderstorm experiments. One Queen Air was modified for its installation. This cooperative NCAR-Bendix effort made it possible to develop specifications for an airborne weather research radar system.

We have tested and/or calibrated a number of sensors and transducers and have engineered them for use on NCAR aircraft. These include the following:

Reverse flow temperature probe
Absolute pressure transducer
Dynamic pressure transducer
Bulova servo altimeter
Time counter reference system
Axial flow temperature system
Hot wire liquid water device
N-1 compass system
High capacity venturi system
Time lapse 16 mm camera system

Aircraft installation engineering of a Brown foil particle sampler is being completed.

Several sensors are currently under evaluation or in the preliminary design or proposal stage:

Bendix dew point hygrometer
Wet bulb element
Radar altimeter
Doppler navigation radar system
Ku-band weather avoidance radar (RDR-100)
Vertical scanning Ku-band weather radar
Prototype liquid water content device
Radio altimeter
Improved temperature sensor
Prototype precipitation particle sampler

Aircraft-instrument interface problems have been reduced by modifying the Queen Airs to provide additional locations for sensor installations. These modifications have markedly increased the usefulness and versatility of the Queen Airs as research platforms.

Data Recording

The ARIS ground station was completed early in the year, and has been used during several research programs. A second airborne data-recording system was procured, with several modifications that enhance operation of the equipment in the airplane. Similar modifications were retrofitted to the first airborne system. A portable ground station was established to allow playback and limited analysis of data in the field. This capability will be important for the Line Islands Experiment, to be conducted in the Pacific in early 1967.

During 1966, ARIS equipment was used to record and handle data from nine research flight programs. Through computer-compatible output tape from the ground station, ARIS equipment made it possible to take advantage of capabilities of NCAR's 6600 digital computer and its dd80 microfilm digital plotter, and to provide scientists with excellent data in convenient form within short periods of time.

Parameters which have been successfully recorded on ARIS are:

- Air temperature: derived from a platinum resistance element mounted in a reverse flow housing, with corrections for dynamic heating automatically made in the computer reduction program; resolution 0.05°C.

- Static pressure: derived from a Pace pressure transducer; resolution 1.2 mb.

- Air speed: derived from a Pace pressure transducer in the pitot system with corrections for temperature and pressure automatically made in the computer reduction program; resolution 0.2 mph.

- Dew point temperature: derived from a Bendix hygrometer; resolution 0.1°C.

- Magnetic heading: derived from an N-1 compass; resolution 0.36°.

• Along-heading velocity: derived from a General Precision AN/APN-153 (V) doppler navigation radar; resolution 0.4 knot.

• Across-heading velocity: derived from the doppler navigation radar; resolution 0.4 knot.

• Ground speed: derived from the doppler navigation radar; resolution 1.0 knot.

• Drift angle: derived from the doppler navigation radar; resolution 0.36°.

• Refractive index: derived from a microwave refractometer; resolution 0.064 N units.

• Electric field potential: derived from cylindrical field mills mounted vertically and horizontally on the aircraft.

• Infrared temperature: derived from a Barnes engineering radiometer.

OPERATIONS

Flight Services

Twenty-two research programs were supported by the Facility during 1966 (compared with 13 projects in 1965). Although we flew simultaneous programs whenever possible, varied scientific objectives made it necessary to provide 18 different instrumentation configurations. We conducted operations in 12 states, the Bahama Islands, and the eastern Pacific.

• Scientific areas of study for the 1966 flights included:

• Atmospheric composition: aerosols, particulate matter, gases;

• Atmospheric electricity: radio emissions from clouds and lightning, and thunderstorm electric fields, using dropsonde field mills, aircraft-mounted rotating cylindrical field mills, and radioactive probes;

• Thunderstorm structure and dynamics as determined by a specially designed dropsonde or by a Ku-band radar mounted on the aircraft;

• Infrared radiation sensing of lake surface temperatures;

• Cloud physics;

• Atmospheric motion and dispersion of particulate matter by airborne detection of natural (radon) and artificial (zinc sulfide) trace materials;

• Total ozone;

• Atmospheric refractivity and its relationship to other atmospheric parameters; and

• Structure and energetics of the land-sea breeze.

Table 1 lists flights and flight hours.

General Support Services

In May 1964 the Interdepartmental Committee for Atmospheric Sciences assigned an interagency information-exchange function to the Aviation Facility. Facility activities carrying out this function during 1966 were as follows:

• A graduate student summer training program was conducted to acquaint students with capabilities and limitations of aircraft as research tools in the atmospheric sciences. Eight students participated in the program:

Richard P. Augulis, Saint Louis University
James R. Connell, Colorado State University
William R. Cotton, State University of New York, Albany
Claude E. Duchon, University of Texas
James W. Fitzgerald, University of Chicago
Marshall C. Hudson, University of Minnesota
Noel B. Plutchak, Lamont Geological Observatory; Columbia University
John L. Vogel, Saint Louis University

• Plans for an Atmospheric Research Aircraft Instrumentation Workshop and Symposium

Table 1

Universities	No. of Flts.	Flt. Hrs. *
University of Arizona		
Thunderstorm Electrification (Evans)	31	52.00
New Mexico Institute of Mining and Technology		
Cloud Electrification (Moore) } Radon Study (Wilkening) }	30	46.00
University of Maryland		
Ozone Study (Bettinger)	1	3.50
University of Texas		
Sea-Breeze (Eddy)	14	36.25
University of Wisconsin		
Atmospheric Dust (Bryson)	3	4.25
Radiometry (Ragotzkie)	38	122.00
Sferics Studies (Rossby)	16	51.75
Radio Wave Propagation (Sargeant)	25	73.50
	158	389.25
Laboratory for Atmospheric Sciences		
Thunderstorm Dynamics (Bates)	8	14.75
Isotope Studies (Blifford, Ehhalt, and Shedlovsky)	117	364.50
Thunderstorm Dropsonde (Bushnell)	21	40.25
Atmospheric Attenuation (Fischer)	4	6.00
Mountain Wave (Lilly)	3	5.50
Aerocolloidal Sampling (Rosinski)	109	243.00
Cloud Physics (Squires)	58	41.00
	320	715.00
Aviation Facility		
Sensor Test and Evaluation (Brown)	72	124.50
ARIS Development/Test (Dascher)	6	5.50
Observer Training	4	7.25
	82	137.25
Other		
Bureau of Reclamation (Bollay)	46	60.00
Hailswath	22	45.25
	68	105.25
Grand Total	628	1346.75

* Including ferry time to and from projects.

were initiated, and resulted in meetings in Oklahoma City on 17 and 18 November. The symposium was sponsored by NCAR, ESSA, and the American Meteorological Society; the Federal Aviation Agency was host. Approximately 150 delegates from universities, industry, and governmental and private research groups met to discuss the use of aircraft in air motion studies, cloud physics, and kinematics.

- We continued to correspond with many U. S. users of research aircraft; we also established contacts with the National Aeronautical Establishment of Canada, the Meteorological Research Flight of Farnborough, England, and the Institute for Atmospheric Physics (DVL), Munich, Germany.

- We sponsored seminars by Donald Lenschow of LAS and H. G. Muller, director of DVL.

Research

The Aviation Facility initiated plans to enlarge its research effort in sensor development and testing, and to expand the scope of in-house research, enabling the Facility staff to pursue lines of investigation commensurate with their interests and capabilities.

PLANS

The Facility Five-Year Plan (FY 67-71) of December 1966 is available under separate cover. Highlights of the plan for 1967 are as follows:

<u>Development:</u>

- Procurement, modification, and instrumentation of a light twin-engine jet aircraft (Sabreliner);

- Continued development of permanent operating base facilities;

- Completion of a feasibility study of light-wing-loading aircraft, helicopters, and drones as atmospheric research tools;

- Continuation of a feasibility study of aircraft-launched constant level (superpressure) balloons;

- Completion of tests of common-use humidity sensors, radar altimeters, doppler radar systems, Ku-band radar;

- Procurement of inertial navigation system components;

- Procurement and modification of helical-scan weather radar;

- Testing of NSME distance-measuring equipment.

<u>Operations:</u>

- Continuation and expansion of flight support to both NCAR and university community programs, with at least 1800 research flight hours during 1967;

- Continuation of flight tests in support of Facility development programs;

- Expansion of the summer university student training program;

- Organization of an atmospheric research aircraft fly-in and instrumentation symposium in the Denver/Boulder area late in 1967;

- Updating of the catalog for aircraft and instrumentation in atmospheric research; and

- Expansion of the internal Aircraft Facility research program.

FIELD OBSERVING FACILITY

INTRODUCTION

In 1966 the Field Observing Facility (FOF) became a joint-use facility, available to non-NCAR scientists. An advisory panel was established and met on 29 April and 3 October.

The number, scope, and complexity of FOF activities increased rapidly during the year. Some of our major programs were hampered by failures due to unreliable sensors and other equipment obtained as surplus. Greatly increased demand for field support during the summer over-extended our resources. Delays in "go-ahead" decisions reduced our lead-time for programs such as Hailswath and the Line Islands Experiment. The FOF advisory panel suggested that crash programs were likely to become a normal way of life for the FOF, a prediction borne out at year's end when the FOF was devoting over half of its total effort to the Line Islands Experiment, first proposed in August 1966.

NCAR FIELD PROGRAMS

Scottsbluff Upper Air Soundings

The FOF obtained radiosonde and ozonesonde data at Scottsbluff, Nebraska, and Limon, Colorado to support the isotope geophysics program of LAS. The entire operation was coordinated with NCAR and USAF aircraft. The Scottsbluff operation has required permanent assignment of a GMD system at the Scottsbluff Airport.

Moutain Wave Study

In support of Lilly's observational study of mountain waves, FOF maintained a network of seven wind-recording systems, and tracked transponder-equipped superpressure balloons across the continental divide. During November the M-33 tracking radar was moved from Marshall to Gunbarrel Hill, northeast of Boulder, where there is a better view of the continental divide.

To improve transponder balloon launches, we moved a heated trailer to the launch site near Granby Reservoir, and provided telephone service between the trailer and the tracking radar. Our new mobile radio-equipped launch truck gives a wide choice of launch sites.

Mass Spectrometer

The FOF repaired and redesigned a radio-frequency mass spectrometer, which is being used in Lodge's photochemical project as a gas analysis tool.

Balloon Facility

In conjunction with the Stratoscope balloon flight at Palestine, Texas, the FOF provided daily GMD rawin soundings up to 80,000 ft and special rabals to 3,000 ft, beginning in mid-April and continuing for about five weeks until the transition from winter to summer wind regimes.

Balloon Facility experiments at the Marshall site, evaluating balloon launching techniques, were supported by FOF. Our staff also assisted the Balloon Facility in a series of GMD flights in southern Brazil, in support of the eclipse expedition during November.

Storm-cell Radar Reflections

We assisted in a cooperative study with the Bureau of Reclamation aimed at correlating storm-cell radar reflectivity with data from existing ground precipitation stations. Radar data were obtained by gated video from a modified M-33 radar. Winds aloft, concentration of freezing nuclei, and surface precipitation were studied.

Puerto Rico Cloud Forest

The FOF is cooperating with Harvard's Arnold Arboretum in an ecological study of a dwarf forest on 3300-ft Pico del Oeste in eastern Puerto Rico. The botanical part of the study is directed by Dr. Richard Howard and is sponsored by the National Science Foundation. Harold Baynton of FOF is directing the meteorological part of the study. Temperature, humidity, short-wave radiation, and rainfall data are collected. Anemometers above and below the forest canopy, a wind vane above the canopy, and a recording cloud-water collector are also in operation.

With equipment almost continually in cloud, we are experiencing humidity-induced failures. Suggestions from Doyne Sartor and Paul Eden of LAS have helped greatly in selecting and maintaining equipment.

Raingage Network

Julian Pike is developing improved methods of measuring excessive rates of rainfall. Five tipping-bucket gages installed along a diagonal of the Marshall field site now record their outputs on separate tracks of an Esterline-Angus event recorder. Although we have not yet had rain of cloudburst proportions, results are encouraging.

Late in the year we assembled electronic components to record raingage data on magnetic tape, a different audio frequency being assigned to each raingage. Playback of data through an incremental tape recorder will allow computer processing of the data.

Line Islands Experiment

A complete account of scientific objectives of this experiment is given in the LAS report. The FOF has had the primary responsibility for achieving these objectives. The field study in the Line Islands (1000 miles south of Hawaii) is to take place in February-April 1967. We began procuring sensors and ground-support equipment in October and November. Operational plans and schedules for transporting personnel, material, and supplies are well advanced. The remoteness of the site has demanded great care in planning, which has involved all echelons of the FOF.

Because of short lead-time and complexity of shipping schedules, some sensors and devices will be tested for the first time when they are unpacked in the Line Islands, and disappointments are expected. Such calculated risks are inevitable when large field programs must hold to a fixed schedule with very short lead-time.

NON-NCAR FIELD PROGRAMS

Sferics Emissions from Convective Clouds

For the last three years the FOF has assisted Stig Rossby of the University of Wisconsin in his studies of sferics emissions from convective clouds. During 1966 we designed and built major modifications into an APS-42 radar for this program. This portable, quantitative, 3-cm radar, with photographic data-recording capability, was operated in August to observe developing convective clouds over the Organ Mountains, near Las Cruces, New Mexico. Multi-channel receivers were used to record sferics emission.

Ecology of Niwot Ridge

The Institute for Arctic and Alpine Research of the University of Colorado is continuing research on the ecology of Niwot Ridge, northwest of Boulder. We have assisted this research by lending wind sets, power generators, and field trailers, and by providing wind records from a station on the ridge and another at Gold Hill.

Ozonesonde Program

Since November 1965 we have been operating the Boulder ozonesonde program, part of a world-wide network. We make indirect measurements of ozone concentrations with a Dobson spectrophotometer, and direct measurements using balloon-borne chemical ozonesondes. During 1966, we carried out one to three ozonesonde flights per week, in collaboration with the Air Force Cambridge Research Laboratories and ESSA.

Hailswath

A cooperative field study under the auspices of the National Hail Modification Research Program was carried out in South Dakota, Nebraska, and Colorado during the summer of 1966. The FOF provided Richard Schleusener of South Dakota School of Mines and Technology with a 10-cm quantitative radar consisting of a hybrid M-33 transmitter with a narrow-beam 10-ft parabolic reflector mounted on a Nike tracking-antenna pedestal. To improve radar coverage in the study area, we also placed an M-33 system at Hemingford, Nebraska; it was maintained by the FOF and South Dakota School of Mines, and operated jointly with Chadron State College, Chadron, Nebraska.

Equipment Loans

During 1966, the FOF loaned equipment to many non-NCAR scientists and institutions. Some of these are listed below:

- Colorado State University: An operations van, GMD ground station equipment, and spare parts were provided during June, July, and August. Two portable anemometers were loaned for several weeks.

- University of Chicago: We took an M-33 radar to Bemidji, Minnesota for the latter part of the summer for use by Roscoe Braham's group to make calibrated reflectivity measurements from growing cumulus clouds. Daily maintenance problems of this aging set were a handicap to this program.

- University of Nevada: We supplied spare parts to the Desert Research Institute for its M-33 and Nike radars.

- University of Colorado: W. L. Flock is using the M-33 radar located northeast of Boulder for studies of radar echoes from migrating birds.

- University of Hawaii: We have installed an M-33 radar on the Hilo campus for a study of the mechanism of warm rainfall.

- U. S. Bureau of Reclamation: We oversee warehousing and distribution of Nike and M-33 radar parts for the Bureau's subcontractors.

- San Jose State College: At the invitation of Albert Miller, we carried out an evaluation flight of the Boundary Profile System in the San Francisco Bay area.

- Seabreeze: In June, Amos Eddy (University of Texas) started the first full-scale investigation of the seabreeze phenomenon, in an area east of Galveston Bay. The FOF provided and operated an M-33 radar and several wind sensors, assisted with operation of an upper air sounding system, and carried out the first evaluation flights of the Boundary Profile System under field conditions.

The Seabreeze experiment was an exercise in frustration. Wind-measuring systems designed for use in micrometeorological studies, where they would be monitored constantly, failed completely when they were operated with only weekly servicing. The old M-33 radar required constant maintenance. A special radiosonde-receiver system, incorporating magnetic tape recording of data, was rushed to completion in our electronics shop and hand-carried to the field site; after performing well for us, it failed when turned over to a field crew. A snapped tether line terminated the evaluation flights of the Boundary Profile System.

Extensive changes in the wind-measuring system, already under way, will result in improved reliability. Continuing development of the Boundary Profile System may (depending on progress in early 1967) provide an operational system for the June 1967 Seabreeze experiment. The FOF and its advisory panel recognize that the M-33s are nearing the end of their useful life and must soon be replaced.

FACILITIES

In support of research programs, the FOF offers shops, field sites, vehicles, communication systems, and a steadily growing variety of meteorological sensors. Although military surplus equipment remains in our inventory, we are acquiring new equipment to replace it and to meet other requirements for reliable, portable sensors. We still lack a wind tunnel and environmental chambers.

Laboratories and Shops

The FOF maintains an electronics laboratory fully equipped for circuit design, prototype fabrication, modification to standard components, and calibration, and an instrument development laboratory, in which precision parts are fabricated.

A mechanical shop is maintained at Marshall for servicing and modifying field vehicles, power generators, and mechanical parts of radars and GMD stations.

Field Sites

With the move to the new NCAR Laboratory, the wisdom of developing the Marshall field site has been confirmed. We have located the ozonesonde program there, and are transferring other functions. The site consists of 79 acres about five miles southeast of Boulder.

A field site is also maintained at New Raymer, Colorado, in support of the cloud physics programs of NCAR and Colorado State University. Through a rental agreement between the FOF and the Institute for Arctic and Alpine Research, NCAR scientists can carry out research programs on Niwot ridge.

This fall we leased a new radar site a few miles northeast of Boulder, on Gunbarrel Hill. The site provides an unobstructed view of the Continental Divide for many miles, and will permit greatly improved transponder tracking of balloons released west of the divide.

Field Vehicles

The FOF has van, flat-bed, 6 x 6, crane, and semi-tractor trucks, and flat-bed, van, low-boy, and special purpose 2- and 4-wheel trailers. Primary power-generating equipment consists of 60 and 400 cps gasoline and diesel units. We lease special vehicles when necessary to support field programs.

Communications

The FOF provides communication equipment for scientific programs. A standard item is the 150-172 Mc VHF system, with both mobile and base stations. We are responsible for the vital communication links that will coordinate the Line Islands program, and for liaison between NCAR and regulatory bodies such as IRAC and the FCC.

Data Acquisition System

After an intensive design study, the FOF has ordered a data acquisition system that will accept many of the common data formats from field sensors and convert these to a format that may be introduced into the Control Data 6600 computer for processing.

Sensors

The items listed below include sensors purchased for the Line Islands Experiment. Many of these sensors listed are committed for many months, but all become available from time to time to support new projects.

- Wind systems:

  7 all-purpose, battery-powered systems
  27 micrometeorological systems (on loan)
  2 anemometers totalizing on attached dial
  4 tachometer generator anemometers
  4 UVW systems
  2 aerovanes, indicating only
  1 two-anemometer system totalizing on impulse printer
  8 mechanical weather stations
  1 Belfort portable system

- Pressure sensors:

  1 mercury barometer
  1 Paulin system portable microbarometer

2 altimeters, 0 to 16,000 ft
6 microbarographs

- Rainfall systems:

6 Belfort tipping-bucket collectors
9 MRI tipping-bucket collectors
1 FOF trough-type tipping-bucket collector
8 weighing raingages

- Radiation sensors:

1 Mark IV indicating Sol-a-meter
2 Mark IV recording Sol-a-meters

- Temperature sensors:

4 hygrothermographs
8 bi-metal thermometers on mechanical stations
1 six-probe, battery powered system, range 50-100F

- Humidity sensors:

1 psychron
several sling psychrometers

- Upper air sensors:

1 Dobson spectrophotometer for indirect measurement of ozone concentration
3 GMD sets for rawinsondes
3 FMQ-2 radiosonde receivers
2 theodolites

- Radars: Most requests for radar support have been met with the M-33 systems. However, since the M-33s are wearing out and spare parts are being consumed, replacements will soon be needed. The FOF Advisory Panel has recommended that the FOF (1) make plans for a versatile weather surveillance radar, with the objective of having a prototype built and in service by FY-69; and (2) develop a plan for radar equipment suitable for tracking transponder targets, with the objective of having a prototype built and in service by FY-70.

Serviceable radars of the FOF include:

5 M-33s
1 quantitative 10-cm hybrid M-33
1 APS-42

In unknown or unserviceable condition are:

2 M-33s
2 APS-44s
2 doppler (CW) 10-cm sets
1 CPS-9

Boundary Profile System

The FOF has been supporting the development of a tethered system for profile studies of temperature, humidity, and wind in the lowest 5000 ft of the atmosphere. A year ago it appeared that a satisfactory vehicle had been developed, and tests of the system awaited the completion of a telemetry system. In evaluation tests carried out last summer near Galveston and San Francisco, vehicle performance was disappointing but the telemetry system worked satisfactorily. Work is continuing on this system.

PERSONNEL

Our professional and technical staff numbers about twenty. We employ casuals from time to time to accommodate seasonal loads, and we have contracted with Western Scientific Services, Incorporated, to assist with transponder flights of the mountain wave study and with upper air soundings at Scottsbluff, Nebraska.

Our visitor program has proven of real benefit. From June to August, Stig Rossby and Edward Eloranta, of the University of Wisconsin, worked closely with us on Rossby's study of sferics emissions from convective clouds. Robert Read, of San Jose State College, spent two weeks in July and August studying measurement of humidity and evaporation in the tropics. Gerald Gill of the University of Michigan, visiting from August to December, gave us valuable assistance in a wide range of instrumentation problems.

FUTURE PLANS

For the immediate future we are heavily committed to the Line Islands Experiment. We have begun planning for the Barbados experiment in the summer of 1968. The mountain wave study, the Puerto Rican study, the Raingage Network, and Seabreeze will continue into 1967. Future plans of the National Hail Suppression Research Program are not yet clear, but further commitments of the FOF are highly probable.

DESIGN AND PROTOTYPE DEVELOPMENT FACILITY

INTRODUCTION

In July 1966, an organization change created the Design and Prototype Development Facility, which includes the Machine Shop, the Mechanical Design group, the Glass Shop, and an electronics shop. The new organization affords a logical, efficient, and workable concept in keeping with the growth of NCAR and the functions of the individual groups. It forms an integrated facility capable of solving complex instrumentation problems within the atmospheric sciences.

Work performed has gradually shifted from construction of small laboratory apparatus with minimum formal design to large, more sophisticated projects which require detailed design and drafting and formal scheduling techniques.

DEVELOPMENT

The design staff moved to the NCAR Laboratory late in September and the machine shop late in December. Building modifications in the machine shop and the glass shop included partitioning of specific functional areas and installation of suspended ceilings for dirt control.

During 1966 our staff increased from 18 to 22-1/2. Space continues to be a problem, especially as the design staff increases.

PROJECTS

The list below indicates projects which required formal design and drafting, plus machine shop work, and shows the variety of our work and, in general, who our customers are. It includes projects started or in progress during 1966, but does not show small jobs done from sketches without formal drawings. Two of the projects were particularly demanding: the Cryogenic Whole Air Sampler for Martell and the Ebert-Fastic Double Monochromator for Shelden.

Project	For
Cloud Camera	Lilly (LAS)
Coupling	Hauser (FAL)
Condenser	Lazrus (LAS)
Temperature Probe	Brown (FAL)
Camera Rewind	Sartor (LAS)
Bellows Housing	Blake (LAS)
Launch Trailer	Angevine (FAL)
Mass Spectrometer Parts	Sheesley (LAS)
Impactor	Wartburg (LAS)
Evacuated Optical Test Tunnel	Ross (HAO)
Anemometer	Rex (FAL)
Satellite Coronagraph	Ross (HAO)
Camera Mount	Ewy (Admin.)
Radar Scope Camera	Fuchs (FAL)
Sample Bottle Racks	Bullock (FAL)

Project	For
Field Meter Mounts	Hinkleman (FAL)
Condensation Trap	Baynton (FAL)
Water Tanks	Busch (FAL)
Battery Cases	Busch (FAL)
Spiral Drop Separators	Brown (FAL)
Doppler Radar Mount	Brown (FAL)
Static Discharge Release	Bullock (FAL)
Search Radar	Saum (FAL)
Oxygen Cart	Beabout (FAL)
Sequential Sampler	Langer (LAS)
Automatic Hail Sampler	Goyer (LAS)
Reflector Mount	Finke (FAL)
Refractometer Caving Housing	Brown (FAL)
Small Air Scoop	Finke (FAL)
Sonde Test Chamber	Glover (LAS)
Aircraft Nose Boom	Brown (FAL)
Steerable Parachute Control	Bilhorn (FAL)

Project	For
Diffusion Batteries	Squires (LAS)
Launch Truck	Shipley (FAL)
Sample Valve	Bainbridge (LAS)
Cloud Gun	Squires (LAS)
Cryogenic Whole Air Sampler	Martell (LAS)
Ebert-Fastic Double Monochromator	Shelden (LAS)

The Machine Shop, in cooperation with the Boulder Valley RE-2 Vocational Trades School, employed four trainees from the school for the summer months. They worked on special projects, including the Rocket Air Sampler and new stock and material racks for the Mesa shop, and assisted the regular machinists. We evaluated this activity as a possible pilot program for the future, and at the request of the school system made constructive suggestions for the school courses.

PROGRAM ON APPLICATIONS ANALYSIS

The Program on Applications Analysis was established during 1966. Its purpose is to study and evaluate meteorological influences related to human populations. The group now consists of three scientists. Three projects have been undertaken:

- Preparation of a report to the National Science Foundation titled "The Human Dimensions of the Atmosphere" was started in June 1966. This study reviews knowledge in the social sciences and recommends future needed work in identification and measurement of the impacts of weather and climate on human activities. It is being conducted by a group of twelve social scientists, under contract to NCAR. The report will be submitted in June 1967.

- Assistance in the preparation of plans for a national hail suppression and research program involved one member of the group through the last part of 1966.

- A site selection study for an astronomical observatory was initiated. This work involves analysis of astronomical research as a system, and search for meteorologic knowledge of the processes which affect optical telescopic observations. It will continue through 1967.

FACILITIES LABORATORY PERSONNEL, 1966

DIRECTOR'S OFFICE

Management

Daniel F. Rex, Director

Professional

Charles A. Palmer, Jr.

Support

Natalie Miller

SCIENTIFIC BALLOON FACILITY

Management

Vincent E. Lally, Superintendent (to GAMP* in November)
Frank E. McCreary, Jr., Superintendent
Alvin L. Morris, Manager

Professional

Jack M. Angevine
Harold L. Baker
Oscar L. Cooper (from December)
Robert W. Frykman (to GAMP in November)
Robert S. Kubara
Ernest W. Lichfield (to GAMP in November)
George P. Mellor (to May)
A. Brewster Rickel (to GAMP in November)
Alfred Shipley
James M. Shoemaker (from April)
Justin H. Smalley (from April)
Ronald L. Snyder
Samuel B. Solot (to GAMP in November)
John W. Sparkman, Jr.
Karl H. Stefan (from January)
Marcel L. Verstraete (to GAMP in November)
John C. Warren

*Global Atmospheric Measurement Project

Support

Edward E. Bishop (to April)
Neil Carlson (to GAMP in November)
Mack O. Gore (from January)
Clinton Hankins
Elizabeth P. Holdsworth
Lionel L. Johnson
Marion L. Luly
Tommie R. Lumpkin
Della Lynch (from September)
William C. Paschall
Jim L. Starry
Lettie M. Wright (to September)

GLOBAL ATMOSPHERIC MEASUREMENT PROJECT (GAMP)

Management

Vincent E. Lally

Professional

Robert W. Frykman
Ernest W. Lichfield
A. Brewster Rickel
Samuel B. Solot
Marcel L. Verstraete

Support

Neil Carlson

COMPUTING FACILITY

Management

Glenn E. Lewis, Head

Professional

Jeanne Adams
Robert P. Biro
Margaret A. Drake
Chester W. Ellis
William Frye (from July)

David Fulker (from February)
John M. Gary
Grant Gray (from July)
Sylvia Hargreaves
Roy L. Jenne
Dennis Joseph (from September)
Alan C. Kay (to July)
David L. Kitts
Gary O. Meeker (to July)
Jack H. Miller
Bernard T. O'Lear
Joseph E. Oliger
Gerard Roach (to August)
David Robertson
Paul A. Rotar
Paul N. Swarztrauber
Joyce A. Takamine
W. Hugh Walker
Nancy Werner (from December)
Larry D. Williams
Donald G. Williston
Robert D. Working (to November)

Support

Donald Austin
Betty Bloom
Carol Beardsley
Richard J. Frank
Wendell A. Franks (to May)
William F. Jones (from April)
Benjamin J. Klepac
Walter A. Lukasik
Dorrit Nesmith
Robert Niffenegger (from March)
Richard L. Patrick
Bonnie Pieper
Joyce Reed (from September)
Georgianna Short (to February)
Judith Slater (from March)
Georgia Sprague
Raymond Wehry (from September)

NCAR RESEARCH AVIATION FACILITY

Management

John W. Hinkelman, Jr., Manager

Professional

Robert G. Beabout
Cleon J. Biter (from June)
Edward N. Brown, Chief, Flight Operations Group
Frank A. Brunot (from January)
J. William Bullock, Chief, Flight Operations Group
Albury J. Dascher
Denford Finke (to May)
William F. Hines (to February)
Robert G. Knollenberg (from February)
Loyd E. Newcomer (from March)
Gene D. Prantner, Chief, Research Projects Group
Lester M. Zinser (from June)

Support

Melvin E. Busch
Toni A. Chapman (from September)
James P. Hauser (from February)
Ursula Hieke (to September)
J. Clyde Hudson

FIELD OBSERVING FACILITY

Management

William S. Lanterman, Jr., Manager

Professional

Harold W. Baynton
Donald A. Eklund
George O. Langer (from March)
Julian M. Pike (from June)
George H. Saum, Jr.
Jack D. Tefft

Support

Charles Amen
William W. Bragg
Peter Crooimans (to July)
Leo Crouch
Roy B. Eis

Edward A. Elsberry (from April)
Raymond J. Figaro (from March)
Betty L. Gafvert
Robert B. James (from April)
Jerry M. Janssen
Lionel Johnson (to September)
Brian W. Lewis
Robert McBeth (from September)
Dale B. McKay
Alan L. Sorenson

DESIGN AND PROTOTYPE DEVELOPMENT FACILITY

Administration

H. Paul Johnson, Manager (professional)
Judith Steinacher

Electronics

Arden Buck, Electronics Engineer (professional)
Milton Dobbs, Electronics Technician

Mechanical Design

Charles Catlin
Michael Howard
Fred Knoblock
Edward Lambdin
Ben Novak

Machine Shop

Marvin Hewett, Shop Supervisor
Hayden Mathews, Shop Foreman
Earl Morrison, Clerk
Edmund Abram
Page Baptist
Jack Crowther
William Dombrowski
Owen Evans
Henry Geisert
Alvin Helfrich
Allen Price
Orvil Starr
Russell White
Frederick Zimmer

Glass Shop

Geza Dombi

PROGRAM ON APPLICATIONS ANALYSIS

Management

Thomas W. Bilhorn, Manager

Professional

Carl Brandauer (from September)
Nelder Medrud, Jr. (from September)

Support

Phyllis Peterson (from September)

FACILITIES LABORATORY REFERENCES*

* Adams, J. C., 1966: "Computing can be fun! -or- A technique for teaching scientific programming," informal report, NCAR Computing Facility, 9 pp.

Aviation Facility Manual, 1965: operational manual, NCAR Aviation Facility, 10 February, 32 pp.

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* Dascher, A. J., 1966: NCAR Aircraft Research Instrumentation System (ARIS), informal report, NCAR Field Observing Facility, January, 8 pp.

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* Dütsch, H. U., 1966: Two Years of Regular Ozone Soundings over Boulder, Colorado, NCAR TN-10, 443 pp.

* Edwards, C. P., 1966: Boundary Layer Profile Measurement System, NCAR TN-16, E. Bollay Assoc., Inc., Boulder, Colorado, 7 pp.

* ______, 1966: Boundary Layer Profile Measurement System Engineering Report, NCAR TN-17, E. Bollay Assoc., Inc., Boulder, Colorado, 39 pp.

* Gary, J., 1966: "A generalization of the Lax-Richtmyer theorem on finite difference schemes," J. SIAM Numer. Anal. 3, No. 3, 467-473.

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* ______, 1967: "Wetterballone für weltweite Messungen," UMSCHAU in Wissenschaft und Technik, 15 January.

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* Lichfield, E. W. and R. W. Frykman, 1966: "GHOST balloons riding the skies will report the world's weather," Electronics, 28 November, 98-106.

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* ______, 1966: Balloon Shapes and Stresses Below the Design Altitude, NCAR TN-23, 19 pp.

Zopf, David, 1965: "Airborne Zinc Sulfide Detector Test," E. Bollay Assoc., Inc. informal technical summary, April.

* Zwack, J. R. and R. C. Brown, 1966: Re-Evaluation of Tapes for Reinforcing and Repairing Polyethylene Balloons, NCAR TN-23, Minnesota Mining and Manufacturing Co., St. Paul, Minnesota, 40 pp.

Administrative and Support Services

ADMINISTRATIVE AND SUPPORT SERVICES

During 1966 the Administrative and Support Services Division was heavily involved in the planning and execution of the move to the new NCAR Laboratory. The formidable task of transferring the staff and equipment of all NCAR divisions except the High Altitude Observatory began in September and was virtually complete by the end of December.

We continued to meet the growing demands of the research and facilities programs by providing direct support services. In keeping with the general expansion of NCAR, there was a steady increase in the activities of the Publications, Technical Illustration, Printing, and Photographic Departments. As a result of the move to the new building the functions of the Library, which had hitherto been restricted by lack of space, were greatly expanded. During the year, the Library collection grew to a total of nearly 24,500 items -- 6,500 books, 6,000 volumes of journals, and 12,000 reports -- an increase of almost 50%.

We established a Public Information Office to handle the varied aspects of NCAR public and press relations. Another notable addition to the services provided by the Division is the NCAR Cafeteria, which opened in November.

Conferences and Visiting Scientists

CONFERENCES HELD AT NCAR, 1966

Project Hailswath

22 January 15 participants

Sponsored by the National Science Foundation, the South Dakota School of Mines and Technology, and NCAR.

First Conference on Tropical Energetics and Synchronous Meteorological Satellites

28-29 January 70 participants

Sponsored by NCAR.

Committee on Atmospheric Sciences, National Academy of Sciences

6-7 April 18 participants

Sponsored by the National Academy of Sciences.

International Conference on Condensation Nuclei

16-17 May 36 participants

Sponsored by NCAR.

Task Group on Human Dimensions of the Atmosphere

20-21 May 11 participants
24-25 October 25 participants

Sponsored by the NCAR Program on Applications Analysis.

TROMEX Steering Committee

24-25 May 41 participants
8-12 August

Sponsored by NCAR.

Summer Colloquium on Various Aspects of Thermal Convection

5 July - 12 August 41 participants

Sponsored by the NCAR Advanced Study Program. (Proceedings will be published as NCAR Technical Note 24, Thermal Convection: A Colloquium.)

National Hail Modification Research Program Steering Committee

2 October 12 participants

Sponsored by NCAR.

American Astronomical Society Special Meeting on Solar Astronomy

3-5 October 117 participants

Sponsored jointly by the National Bureau of Standards, the Environmental Science Services Administration, the Joint Institute for Laboratory Astrophysics, the University of Colorado, and NCAR.

National Aeronautics and Space Administration Fluid Mechanics Advisory Committee

14-15 November 18 participants

Sponsored by NASA.

VISITING SCIENTISTS, 1966

Abdul J. Abdullah, University of Baghdad, Baghdad, Iraq

Bernice Ackerman, University of Chicago, Chicago, Illinois

Ernest Agee, University of Missouri, Columbia, Missouri

S.-I. Akasofu, University of Alaska, College, Alaska

Fred Alyea, Colorado State University, Fort Collins, Colorado

Tomio Asai, Meteorological Research Institute, Tokyo, Japan

Richard P. Augulis, Saint Louis University, St. Louis, Missouri

Dennis G. Baker, Massachusetts Institute of Technology, Cambridge, Massachusetts

William Barchet, Drexel Institute of Technology, Philadelphia, Pennsylvania

Fred C. Bates, Saint Louis University, St. Louis, Missouri

John R. Bates, Massachusetts Institute of Technology, Cambridge, Massachusetts

Jeffrey C. Bauer, Colorado College, Colorado Springs, Colorado

Edward R. Benton, University of Colorado, Boulder, Colorado

Roy Berggren, Swedish Meteorological and Hydrological Institute, Stockholm, Sweden

William Blumen, University of Oslo, Blindern, Norway

Rumen D. Bojkov, Meteorological Services of Canada, Toronto, Canada

Kenneth C. Brundidge, Texas A & M University, College Station, Texas

Gregory C. Bullen, University of Colorado, Boulder, Colorado

J. Graham Bunting, Hartley Victoria College, Manchester, England

Alfred E. Bussian, University of Michigan, Ann Arbor, Michigan

Theodore W. Cannon, Oregon State University, Corvallis, Oregon

Alfred S. Carasso, University of Wisconsin, Madison, Wisconsin

S. H. Chiu, New York University, New York, New York

James R. Connell, Colorado State University, Fort Collins, Colorado

William R. Cotton, State University of New York, Albany, New York

John J. DeLuisi, Florida State University, Tallahassee, Florida

Dusan Djuric, University of Belgrade, Belgrade, Yugoslavia

Claude E. Duchon, University of Texas, Austin, Texas

Hans U. Dütsch, Federal Institute of Technology, Zurich, Switzerland

Dieter Ehhalt, University of Heidelberg, Heidelberg, Germany

Edwin W. Eloranta, University of Wisconsin, Madison, Wisconsin

Mariano A. Estoque, University of Hawaii, Honolulu, Hawaii

James W. Fitzgerald, University of Chicago, Chicago, Illinois

G. Brant Foote, University of Arizona, Tucson, Arizona

S. K. Friedlander, California Institute of Technology, Pasadena, California

Kenneth S. Gage, University of Chicago, Chicago, Illinois

Reiner Gebhart, Technische Hochschule, Munich, Germany

Gerald C. Gill, University of Michigan, Ann Arbor, Michigan

Peter A. Gilman, Massachusetts Institute of Technology, Cambridge, Massachusetts

Aldo Giorgini, Colorado State University, Fort Collins, Colorado

Arne Grammeltvedt, Institute of Geophysics, University of Oslo, Norway

Thomas B. Gray, Air Weather Service, Offutt AFB, Nebraska

Jagdish Gupta, University of California, Los Angeles, California

Raymond Hide, Massachusetts Institute of Technology, Cambridge, Massachusetts

T. W. Hildebrandt, Ohio State University, Columbus, Ohio

Jeremy Howell, Parsons College, Fairfield, Iowa

Marshall C. Hudson, University of Minnesota, Minneapolis, Minnesota

L. H. Hutchinson, Joint Task Force Eight, Washington, D. C.

Donald R. Johnson, University of Wisconsin, Madison, Wisconsin

Richard H. Jones, The Johns Hopkins University, Baltimore, Maryland

Joachim H. Joseph, University of California, Los Angeles, California

Joseph L. Katz, North American Aviation Science Center, Thousand Oaks, California

Peter C. Kendall, University of Sheffield, Yorkshire, England

A. A. Kennel, DePauw University, Greencastle, Indiana

Max Kuperus, Space Research Laboratory, Utrecht, The Netherlands

Conway Leovy, The RAND Corporation, Santa Monica, California

Yeong-Jer Lin, New York University, New York, New York

Man-Kin Mak, Massachusetts Institute of Technology, Cambridge, Massachusetts

Roy McCrory, New Mexico Institute of Mining and Technology, Socorro, New Mexico

Donald J. McKenzie, University of Washington, Seattle, Washington

Ronald D. McPherson, University of Texas, Austin, Texas

R. W. Miksad, Massachusetts Institute of Technology, Cambridge, Massachusetts

James M. Mitchell, Indiana University, Bloomington, Indiana

Bruce Morton, University of Manchester, England

T. S. Murty, University of Chicago, Chicago, Illinois

Morris Neiberger, University of California, Los Angeles, California

James J. O'Brien, Texas A & M University, College Station, Texas

Harold D. Orville, South Dakota School of Mines and Technology, Rapid City, South Dakota

Gary D. Parker, Cornell University, Ithaca, New York

Dennis G. Parkyn, University of Cape Town, South Africa

Norman A. Phillips, Massachusetts Institute of Technology, Cambridge, Massachusetts

Arthur Pike, Cambridge University, Cambridge, England

George W. Platzman, University of Chicago, Chicago, Illinois

Noel B. Plutchak, Lamont Geological Observatory, Columbia University, New York, New York

Jean Pwu, University of Manitoba, Winnipeg, Canada

D. B. Rao, University of Chicago, Chicago, Illinois

C. Abhirama Reddy, Andhra University, Waltair, India

David R. Rodenhuis, University of Washington, Seattle, Washington

Stig Rossby, University of Wisconsin, Madison, Wisconsin

Daniel Rousseau, Massachusetts Institute of Technology, Cambridge, Massachusetts

James C. Sadler, University of Hawaii, Honolulu, Hawaii

K. R. Saha, Institute of Tropical Meteorology, Poona, India

Takao Saito, Tohoku University, Sendai, Japan

Peter M. Saunders, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Keith Schofield, University of California, Santa Barbara, California

Roger Schreck, College of Emporia, Emporia, Kansas

E. H. Schroeter, Universitätssternwarte Göttingen, Göttingen, West Germany

Joseph Sela, University of Michigan, Ann Arbor, Michigan

William L. Siegmann, Massachusetts Institute of Technology, Cambridge, Massachusetts

Melvyn A. Shapiro, Florida State University, Tallahassee, Florida

William Slusser, San Fernando Valley State College, Northridge, California

Ralph C. Smith, The University of Keele, Staffordshire, England

Bengt Söderberg, Royal Swedish Air Force, Barkaby, Sweden

Richard C. J. Somerville, New York University, New York, New York

Kvetoslav Spurny, Czechoslovak Academy of Sciences, Prague, Czechoslovakia

William J. Taffe, University of Chicago, Chicago, Illinois

J. J. Taljaard, Weather Bureau, Pretoria, South Africa

James W. Telford, Commonwealth Scientific and Industrial Research Organization, Division of Radio Physics, Sydney, Australia

Aylmer H. Thompson, Texas A & M University, College Station, Texas

Ignaz Vergeiner, University of Innsbruck, Innsbruck, Austria

John L. Vogel, Saint Louis University, St. Louis, Missouri

Robert D. Watson, New Mexico Institute of Mining and Technology, Socorro, New Mexico

Peter A. Webster, Florida State University, Tallahassee, Florida

James A. Weinman, University of Wisconsin, Madison, Wisconsin

David T. Wilkinson, Princeton University, Princeton, New Jersey

David L. Williamson, Massachusetts Institute of Technology, Cambridge, Massachusetts

William P. Winn, University of California, Berkeley, California

Aksel C. Wiin-Nielsen, University of Michigan, Ann Arbor, Michigan

Janet Wood, Concordia College, St. Paul, Minnesota

Michael Yanowitch, Adelphi University, Garden City, New York

Kwang-Sik Yun, National Research Council of Canada, Ottawa, Ontario, Canada

C. Zwaan, Sterrewacht "Sonnenborgh," Utrecht, The Netherlands