NCAR
Research and Facilities
Programs

1965

National Center for Atmospheric Research
Boulder, Colorado
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FOREWORD

This year's report, like those of preceding years, is made up of brief summaries of the research and facilities efforts under way in NCAR's scientific divisions. The summaries were prepared by the Division Directors for our own planning and coordination needs. We know from experience, however, that this report is of interest to scientists outside of NCAR, as it brings together a great deal of information on our current state and progress. Consequently, upon request we will be glad to send copies of this document to interested research workers elsewhere.

At the end of 1964, the staff at NCAR had reached a size and a stability that, with the help of visitors to NCAR, allowed us to focus our effort more consciously on the larger interdisciplinary problems of atmospheric science, especially in the Laboratory of Atmospheric Sciences. We continued to sharpen the definition of these large problems in 1965.

In the Laboratory of Atmospheric Sciences, various scientific groups, in addition to working on a substantial number of separate problems, gave significant attention to the interrelationships of these efforts in the context of three major problem areas, to which we gave priority: (1) the general circulation, (2) the physics of clouds and precipitation, and (3) the life cycles of trace gases and aerosols. These areas, moreover, were increasingly probed for the contributions they could make to the understanding and realistic numerical modeling of the general circulation.

The Advanced Study Program completed its first full year of operation, during which two series of advanced lectures were given, one on statistical hydrodynamics, the second on integral methods for solving stability problems. In addition, a working seminar was conducted on the theory of internal gravity waves, and another on extraterrestrial influences on various levels of the atmosphere. These activities reflect our intention to focus scientific thought and activity on the difficult frontier problems in atmospheric sciences.

An important new instrument, the emission-line magnetograph, was put into operation at the High Altitude Observatory site at Climax, Colorado. With this instrument, the HAO staff have succeeded in measuring the line-of-sight magnetic field in a large number of solar prominences in an effort to define the role of magnetic fields in the support of prominences against solar gravity. The understanding of the influences of the sun on the earth will require an accurate model of the nature of solar activity, and magnetic fields seem to play an important part in every aspect of a solar active region.

In 1965, NCAR's ties with and services to the universities expanded considerably:

- NCAR continued to expand its visitor program and to sponsor conferences on subjects related to atmospheric research (a full list of visitors and conferences is given at the end of this report).
- Seven postdoctoral appointments were made in the Advanced Study Program to allow new Ph.D.'s and other scientists to spend a year at NCAR working on research problems in the atmospheric sciences.
- NCAR's first joint-use facility, the NCAR Scientific Balloon Facility, continued full-scale operation of its flight station at Palestine, Texas. Full-scale operation of joint-use facilities in computing and aviation was also achieved, and a joint-use facility for field observing support was established.
- The UCAR affiliate professorship program got underway; in this program NCAR staff members establish regular ties with universities, normally for periods of about three years. Six senior NCAR staff members are now affiliate professors at six different universities, and several other such appointments are under discussion at this time.

Most of the scientific interchange between NCAR scientists and their colleagues in the universities and elsewhere flows through the normal routes -- papers in professional journals, papers read at meetings, and visits to and from other laboratories. Details of individual scientific programs and bibliographic listings of contributions to the professional literature are included in the division reports that follow. However, NCAR's role in expanding the atmospheric sciences to become commensurate with the national need requires us to pursue other means of communication as well. Therefore, in addition to the many NCAR scientific papers either published or presented at professional meetings during 1965, the NCAR staff gave 88 public lectures on science, 132 invited talks at universities, and four series of lectures or courses at universities.

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As in previous reports, NCAR's goals and purposes are restated here:

> NCAR is a basic research establishment dedicated to the advancement of the atmospheric sciences for the benefit of mankind.
>
> The perspectives and the scientific activities of NCAR are those of a research laboratory devoted to achieving a fundamental understanding of natural phenomena. The scientists in NCAR recognize, nonetheless, that the public funds on which NCAR operates are given in anticipation of public benefit, and they acknowledge an obligation to organize their research with a view to such ultimate benefits, and to cooperate with other agencies in achieving them.
>
> NCAR pursues its goals through the conduct of basic research and through cooperative planning and operation of joint research and facilities programs. These are designed to assist and to extend the atmospheric research and educational efforts of the universities and other research agencies of the nation.
>
> The specific means by which the staff of NCAR seeks to achieve its objectives may be listed as follows:

1. By creating within NCAR a broadly based, interdisciplinary research center whose functions are to pursue the fundamental understanding of atmospheric processes, to encourage postdoctoral education, and to attract talented students to the atmospheric sciences;

2. By serving as a research and facility planning center to aid the development of large-scale research programs involving a number of institutions, or to bring about the creation, under NCAR auspices or otherwise, of needed major facilities for use by several institutions jointly;

3. By managing and operating joint-use facilities, generally in response to the university community, where clearly established national interest dictates, and where no other institution is in a position to provide such facilities more effectively.

The Earth's atmosphere is a crucial world resource and a major determinant of the environment of man. The atmosphere and its variations affect every nation and every walk of life. Improved understanding, prediction, conservation and control of the atmospheric environment assume ever-increasing urgency.

Major advances will not come quickly or easily, but the potential social and economic rewards are so great as to justify an accelerated and continuing national effort. In particular, NCAR shares with other research groups four interrelated long-range objectives that ultimately provide justification for major expenditures of public and private funds:

- To ascertain the feasibility of controlling weather and climate, to develop the techniques for control, and to bring about the beneficial application of this knowledge;
- To bring about improved description and prediction of astrophysical influences on the atmosphere and spatial environment of our planet;
- To bring about improved description and prediction of atmospheric processes and the forecasting of weather and climate;

● To improve our understanding of the sources of air contamination and to bring about the application of better practices of air conservation.

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To this I would only add, this year, that we are concerned, more than ever before, with the importance of bringing about the closest possible coupling of basic research and practical application. In the coming year we intend to take formal steps to create a new activity -- a program in applications analysis -- to facilitate cooperation among NCAR and university people, on the one side, and on the other, our colleagues in private and government laboratories -- with a specific aim to try to reduce the time required to bring new knowledge to a prompt and effective application. We believe that this can be done with benefit to the basic research effort of the country, and as an aid, rather than as competition to, those public and private groups interested in applications of various kinds.

Walter Orr Roberts

Walter Orr Roberts

Director

CONTENTS

Report of the

HIGH ALTITUDE OBSERVATORY

INTRODUCTION

In looking back over the work of the High Altitude Observatory during 1965 we are once again reminded of the nature of scientific research, reminded that progress is slow and that the elation which comes with successful work and new insights is amply balanced by long periods of hard work, little apparent progress, and occasionally out-and-out failures. The reader of the following pages will perhaps detect the feeling of genuine pleasure we have achieved a few times during the year upon making major accomplishments, and we hope we have honestly reported the work for which the successes are still in the future.

We experienced considerable excitement, late in the year, because of two developments in the theory of the atmosphere of the sun and stars. Two staff members, one working with colleagues in Europe, and another working in Boulder on related areas, have achieved new insights and new formulations of the theory of the formation of absorption lines in the spectrum of the sun. The new formulation of the theory itself is a worthwhile achievement, but the excitement stems more from the fact that this new insight suggests that most previous work done on the formation of strong absorption lines is seriously in error. The new work, therefore, must be pursued vigorously to revise much of the theory of the sun's atmosphere with the expectation that the results will be quite different from those we considered fairly well established a year ago, and with the hope that some of the difficulties and inconsistencies which bothered us previously will disappear. The new work has applications far beyond simply understanding the formation of absorption lines, arising from the fact that we use the details of observed absorption lines as a primary technique for investigating the physical conditions of the sun's atmosphere.

During the year we also achieved our ambition to fly our balloon-borne coronagraph twice in fairly rapid succession and in association with a natural solar eclipse. We expected that the eclipse, plus the two properly-spaced flights, would give us new and unique measurements from which we might derive positions of solar features seen at eclipse and information on the time scale of changes in the solar corona. Our expectations are borne out by the observations that we have in hand. These three observations seem likely to remain the best source of information about the structure of the intermediate corona for several years to come.

The balloon flights were not made without a tremendous effort on the part of our staff. The difficulties experienced in trying to fly on a fixed schedule; aligning the instrument properly; overcoming the balloon launch problems; and recovering, repairing, and realigning the instrument for the second flight all have impressed us with the exhausting difficulty of achieving anything like synoptic observations of the intermediate corona with our balloon equipment. The section of this report which describes our plans to investigate alternate ways of observing the intermediate corona perhaps gives an accurate description of our feeling that we have not yet achieved the ideal instrument for such investigations.

On the other hand, our measurements of the inner corona made from our field station in Hawaii have been of higher quality and more extensive than we had hoped. These ground level measurements, interesting in themselves, are also needed to complement measurements of the intermediate corona, and they certainly will be adequate for that purpose.

During the year an administrative transition took place which represents the end of major activity in an important research field for the High Altitude Observatory. In the attempt by the University of Colorado to build upon the graduate educational activities created some years ago by HAO, a few of the staff of the Observatory transferred their appointments to the University of Colorado. Since it is only possible to conduct research programs under the detailed guidance of the scientist who is interested in the results, we accompanied this transfer of personnel by a transfer of the research facilities developed by those scientists leaving the staff, in particular by the transfer of our radio astronomy facilities and instrumentation. The University of Colorado now provides all of the support facility, handles the contract funds, and otherwise operates the North Site where our long-wave radio astronomy has developed over the past eight years. The opportunity exists in the University for the work to be continued on Jupiter, the sun, the ionosphere, atmospheric noise, and perhaps in other areas, and the Observatory arranged to make the transfer in a gradual manner so that no disruption in the activities occurred. The Observatory intends to maintain its vigorous interests in radio noise from the solar atmosphere, but the detailed development of a program will have to await the addition to the staff of the scientists to plan and organize our research effort.

The year 1965 saw a considerable increase in the number of visitors working with us. The visitors came from all over the world and worked in almost every aspect of our research program. The year also saw a continued development of our capability to produce emission in the laboratory to simulate that observed from the sun, and, once again, we feel genuine pleasure at the successes enjoyed in this field of research.

John W. Firor

Director

THE CHROMOSPHERE

LINE FORMATION

At the end of 1964 Athay was computing the expected intensities of the solar emission lines of hydrogen and helium using a new theory which he had developed earlier in the year. The first part of this year, 1965, was spent completing this work. He was able to match the observational data with a relatively simple model chromosphere in which the temperature gradient, dT/dh, was relatively small in the range $25000 \leq T \leq 60000$ but became very large, $dT/dh \simeq 0.1$ (deg cm^{-1}), for $T \simeq 10^5$. This work was essentially complete in March.

Athay spent the greater part of the year in Europe where he shared his HAO appointment with College de France, Observatoire de Nice, and the Max-Planck Institut für Extraterrestrische Physik. His work at each institution reflects the interests of our colleagues at these locations. Beginning in late May, he presented a series of four lectures at College de France. The first three of these were based upon his theory of emission line intensities and its application to the solar, far-ultraviolet spectrum. The fourth lecture was a summary of his attempts to generalize the theory to include absorption lines; these attempts occupied most of his time before leaving for Europe and served as the focal point of his work in France.

Scientific contacts and discussions in Paris and Nice stimulated a careful examination of the relationship between the new theory and previous theories. This resulted in a successful generalization of the theory and brought to light several new ideas relevant to the formation of spectral lines in stellar atmospheres.

The new theory leads to the concept that the line source function, S, which is the ratio of emissivity to absorptivity, is necessarily frequency dependent because photons in the line wings may escape more readily from the star than photons at line center. This fact leads to a systematic drift of photons, still within the atmosphere, from line center into the wings. The neglect of this frequency dependence may seriously alter the solutions for S in a prescribed model atmosphere. A detailed evaluation of the frequency dependence of S is still beyond present capabilities because of a lack of sufficient atomic parameters. However, once the problem is clearly recognized it is possible to redefine S in such a way that it is truly frequency independent. This is done by defining S as the ratio of emissivity integrated over frequency to the absorptivity integrated over frequency. Photon diffusion within the line then no longer affects S. This new S can be evaluated by formulating the equations of radiative transfer in terms of the total intensity (equivalent width) of the line rather than the customary monochromatic intensity. Solution of the resulting equations requires a large computer, such as NCAR's CDC 3600, and will occupy much of the time of Athay and Skumanich during the coming year.

The equations for S clearly cannot be satisfied by published solutions for equations which do not account for photon diffusion within the line. The form of the new equations requires that in certain lines S be less than the Planck function, B, in the surface layers; rise above B in a layer considerably below the level of optical depth unity at line center; and decrease to B at greater depths, as illustrated in Fig. 1. This behavior is expected for lines in which collisional excitations and de-excitations are the dominant source and sink terms and is immediately suggestive of the observed emission peaks in the H and K lines of Ca II and Mg II. For lines in which the major source and sink terms involve transitions to other atomic energy levels there is no longer a requirement that S exceed B at any level.

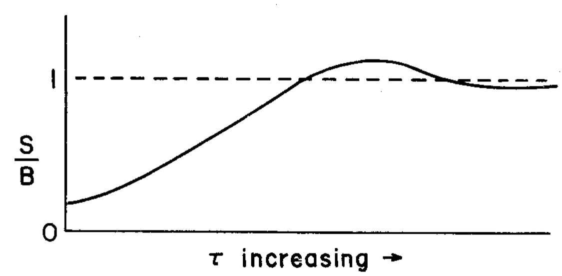


Fig. 1

A further result of the new theory is that the classical assumption of LTE, S = B, is rigorously valid only for lines of zero equivalent width. The extent to which lines of finite intensity mimic the assumptions of LTE must await a detailed solution of the equations.

Late in the report year Skumanich visited Munich to collaborate with Athay in this new integral approach to line formation. Rather than working solely with the zeroth-moment of the radiation field (with respect to angular direction) and its expression in terms of the source function, the new method utilizes the first-moment in addition. By suitable manipulation of the zeroth-moment of the transfer equation one can derive an integral equation for the source function (and hence ultimately the internal as well as external radiation field) which differs as indicated above from existing formulations. This formulation also includes in a straightforward way any possible frequency dependence in the source function. It is hoped that this new approach is more stable than those currently in use. After his return to Boulder, Skumanich began a mathematical study of this equation, with the aid of Jerry Roach, as a preliminary to numerical programming.

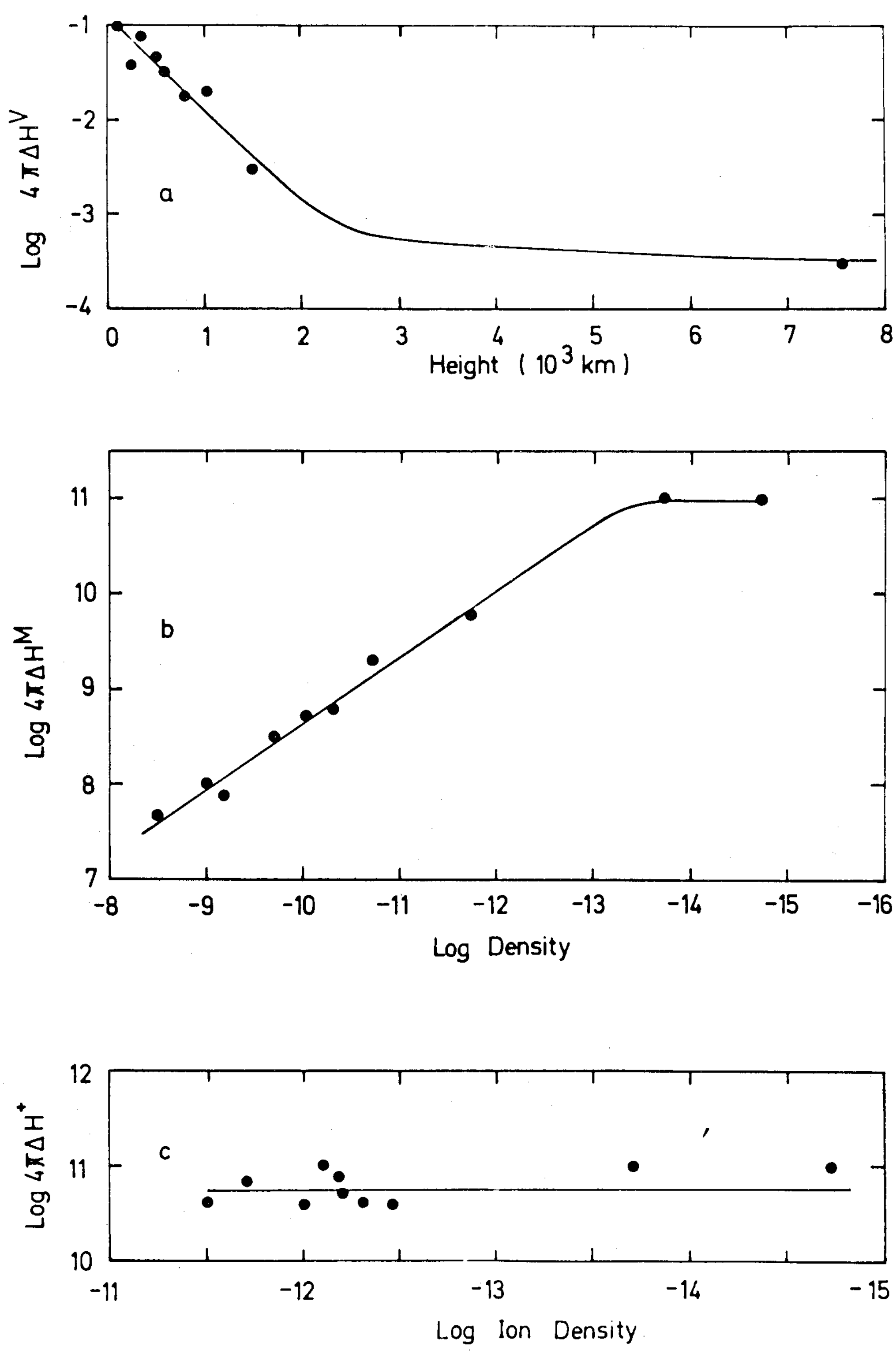
A sidelight of this work of Athay and Skumanich which is of considerable interest is the role of continuum absorption in line formation. It has been widely argued that absorption lines in a stellar spectrum result from the capture of line photons in the continuum. The new theory shows that, in fact, continuum processes add photons to absorption lines and remove photons from emission lines; i.e., continuum processes tend always to restore the spectrum to the continuum distribution. An absorption line, in the new theory, requires the destruction of photons in the line in question as the net effect of collisional excitation and de-excitation and of interlocking with other lines. The reverse is true, of course, for emission lines.

ENERGY BALANCE

The original purpose of Athay's visit to Munich was to work on problems related to chromospheric energy balance. Specifically, he planned to evaluate, as accurately as possible, the rate of energy loss, $4\pi\Delta H$, in the dominant spectral features of the chromosphere. This evaluation requires a separation of the observed radiation flux into the component that is created in the region in question and the component that is simply scattered from the radiation field filtering through from deeper layers. Only the first component contributes to the energy balance. This separation requires an accurate knowledge of S. Unfortunately, the new theory of line formation casts considerable doubt on the validity of published solutions for S, which made the original plans for evaluating $4\pi\Delta H$ impractical.

After reconsidering the basic problem, Athay discovered that by computing $\Sigma\ 4\pi\Delta H$, where the summation is over all transitions ending on a particular energy level, rather than treating each line and free-bound continuum separately, the problem was greatly simplified and could be solved in a meaningful way without a precise knowledge of S. The effect of the summation is to allow the substitution of a net rate of collisional transitions for the net rate of radiative transitions, the former being much easier to evaluate.

By utilizing a combination of computed energy losses from a model chromosphere and radiation fluxes observed at eclipse and from high altitude rockets, Athay was able to derive $4\pi\Delta H$ as a function of height from the base of the chromosphere through the low corona. Previous estimates included only the total rate of energy loss from the chromosphere or corona, or from both. The new results reduce the most widely accepted value of $4\pi\Delta H$ for the chromosphere by about an order of magnitude. This in itself is of importance, since the previous estimates required what seemed to be a much too efficient conversion of mechanical energy into radiant energy. The height variation of $4\pi\Delta H$, however, is of even more interest and showed a surprising feature illustrated in Fig. 2. Whereas $4\pi\Delta H^V$ (ergs sec^{-1} cm^3) and $4\pi\Delta H^M$ (ergs sec^{-1} gm^{-1})



Log $4\pi\Delta H^V$
a
Height (10^3 km)
Log $4\pi\Delta H^M$
b
Log Density
Log $4\pi\Delta H^+$
c
Log Ion Density

Fig. 2

each change by large factors between the low chromosphere and the corona, $4\pi\Delta H^+$ [ergs sec^{-1}(gm positive ion)$^{-1}$] remains essentially constant with height. The rate $4\pi\Delta H^+$, apart from a constant multiplying factor, is essentially the rate of energy loss per proton, or equivalently, per electron. Each of the radiating mechanisms, however, which range from H^- and H to Fe XVI, depends upon the product of electron density, n_e, and ion density, n_i, where the ion is the one giving rise to the observed radiation. Evidently the general rate of temperature rise is such as to eliminate the dependence upon n_i. Such an effect must be imposed by the energy input mechanism. Thus, the constancy of $4\pi\Delta H^+$ suggests that energy is fed into the chromospheric and coronal plasma via the positive ions.

Thermal conduction may also be an important factor in the energy balance in the outer solar atmosphere, particularly in the chromosphere-corona interface where the temperature gradient is large. The fluxes observed in ultraviolet emission lines in the solar spectrum depend upon, among other factors, the thickness of the radiating layer, which in turn depends upon the temperature gradient. Using his theory of line formation, Athay was able to express the observed fluxes in terms of T, dT/dh, n_e, and A, the relative abundance of the parent element of the ion producing the radiation. The observed fluxes were then used to derive A and the relationship between T and dT/dh. The results gave

$$T^{5/2} \frac{dT}{dh} = 3 \times 10^{11}$$

for $1 \times 10^5 \leq T \leq 7 \times 10^5$. Since the coefficient of thermal conductivity is proportional to $T^{5/2}$, this equation corresponds to a constant flow of thermal energy by conduction from the low corona into the upper chromosphere. In the absence of a magnetic field the conductive flux is 5×10^5 ergs cm^{-2} sec^{-1}, which is comparable to the radiant energy flux from the low corona and the upper chromosphere.

A word of caution is needed, however; dielectronic recombinations were ignored in computing the coronal ionization equilibrium. When these are properly included, the constant on the right-hand side of the equation may change by a relatively large factor. Thus the absolute value of the conductive flux is uncertain. It seems unlikely that the inclusion of dielectronic recombinations will markedly affect the exponent on T in the above equation.

The relative abundances found by Athay for C, N, Ne, Na, Mg, Al, Si, P, S, and Fe in the chromosphere and corona are each within 30% of the accepted values for the photosphere. Oxygen was found to be only about one half as abundant in the photosphere as had been supposed. These results are in sharp conflict with results obtained by Pottasch using the same data and a similar method of analysis. The basic differences are of interpretation and of how the abundances should be derived. Pottasch found strong departures from photospheric abundances amounting to as much as a factor of ten for iron. His results have stimulated much debate and have prompted some to attempt detailed theories to account for the supposed abundance differences. The new results indicate that relative abundances may be considered to be constant throughout the solar atmosphere.

LYMAN EMISSION

In another study related to chromospheric emission, Hearn made an interpretation of the total intensities of the Lyman α and β lines from the sun. The profiles of these lines contain much information about the spatial variation of the electron temperature and density but the interpretation is difficult. When only the total intensities are used, the information about the spatial variations is lost and only the mean properties can be obtained, but the interpretation is then much easier.

The interpretation is derived from calculations of the intensities of lines emitted from a uniform finite atmosphere which solve the equations of statistical equilibrium and radiative transfer where necessary for all levels. A finite atmosphere is a valid approximation for the Lyman lines because the temperature of that part of the chromosphere which emits them is high compared with the temperature of the photosphere. The calculations include the contribution by photo-excitation and photo-ionization by the photospheric continuum.

Although the high bound levels do not contribute directly to the intensities of the Lyman α and β lines, they do limit the electron density that can be assumed. As the electron density increases, the mode of populating the low levels becomes dominated by processes of three-body recombination, collisional de-excitation, and radiative cascade through the higher bound levels from the continuum. When this happens, the observed intensity ratio of Lyman α and β cannot be obtained. This electron density limit is about 10^{11} or 10^{12} cm^{-3}, and the observed intensities cannot be interpreted in terms of an electron density higher than this. This limit in the electron density would not be shown by a model of three or four bound levels and the continuum.

A finite uniform atmosphere is specified uniquely by the electron temperature and density and by a size which is conveniently given by the optical thickness measured at the center of the Lyman α line. The two line intensities may be used to determine the optical thickness and electron density for a particular assumed electron temperature, but there is not sufficient information to determine the temperature. The calculations show that the geometrical size of the atmosphere depends very sensitively upon the electron temperature and that with this measurement a well-defined interpretation may be made. Unfortunately no direct measurement of the geometrical size has been made yet, and it is suggested that this would be a valuable measurement. An upper limit of the geometrical size is available from measurements of the total intensity of Lyman α at the 1961 eclipse in the Crimea, where the intensity fell to a very small fraction of the uneclipsed intensity. Assuming that the layer lies between the visible limb of the sun and the projected limb of the moon, the circumstances of the eclipse show that the layer cannot exceed 19,000 km, which means that the electron temperature of the layers emitting Lyman α and β cannot exceed 30,000°K.

This contrasts with earlier interpretations of the Lyman α profile which give a doppler width equivalent to 70,000 to 90,000°K.

It is difficult to place a lower limit on the electron temperature, but if it is 16,000°K the geometrical size of the layer is only 2.5 km, which is probably much smaller than anyone would accept.

LINE REVERSALS

In an effort to understand the influence of various physical factors on the formation of the emission reversal in the K and H resonance lines of Ca^{+}, Skumanich initiated a theoretical study of the formation of absorption lines. In this study he sought solutions to the equation of radiative transfer for various models of stellar atmospheres.

Starting with the Eddington approximation (essentially a two-stream approximation) to the equation of transfer in a plane stratified atmosphere, a single spectral line is assumed to be formed in the presence of continuous absorption. The line source function (ratio of line emission to line absorption) is that for a two-level atom. The second-order equation which is obtained in the Eddington approximation is then transformed to two first-order equations for which the boundary conditions (given at each boundary; i.e., at two separate points) are expressible in mathematically convenient form. The introduction of a finite number of arbitrary frequencies throughout the line (method of discrete ordinates) reduces the frequency quadrature in the source function to a discrete sum, and a vector differential equation with matrix coefficients is obtained directly. Introducing a central difference approximation for the first-order derivatives, a system of linear vector equations is obtained, and these equations are solved directly by means of a variant of gauss elimination. This system of equations was coded for the CDC 3600 by Chester Ellis.

In the two-level atom approximation, two important physical parameters enter into the physics of line formation. The first of these is a measure, ϵ, of the coupling of the atom to the local thermal reservoir (essentially the fraction of all de-excitations which are collisional, usually $\ll 1$) and the second is a measure, r_o, of the strength of the line (essentially the ratio of continuous absorption to line absorption at the center frequency of the line, usually $\ll 1$). A third parameter is the shape of the microscopic line-absorption coefficient.

Skumanich obtained numerical solutions for isothermal, isopycnic atmospheres with a variety of ϵ, r_o values for a gaussian-shaped absorption coefficient (doppler broadening). Comparison of numerical solutions with known analytic ones indicated quite satisfactory agreement (the order of 1 part in 10^5) and also proved useful in determining the effect of various quadrature formulas (for example, Gauss-Hermite, Hermite). A formula developed by Skumanich which includes scattering into the continuum proved superior to the Gauss-Hermite or Hermite formulas.

Others have shown that central emission reversals can be produced by introducing a hotter layer (a chromosphere) above the normal photosphere. Such a situation is represented by a model atmosphere in which the gas temperature falls from some arbitrary value at the surface (characterized by T_{max}) to a minimum somewhere below the surface and then rises inward in normal fashion. Both the position of the minimum and T_{max} were treated by Skumanich as free parameters; T_{min} was held at the solar value of 4000°K. Solutions with such a model for a variety of parameters (ϵ, r_o, T_{max}, τ_c (min)) have been obtained. Once again the microscopic absorption profile was taken to be gaussian, but (and this is where the present work differs substantially from earlier analyses) the doppler broadening parameter (i.e., the dispersion in the gaussian profile) was allowed to vary with the local gas temperature.

Preliminary analysis indicates that the important parameter which governs the nature of the emission reversal is $\tau_{min}\epsilon$. Here τ_{min} ($= \tau_c(\text{min})/r_o$) is the location of the temperature minimum measured in units of the optical depth at the line center (the basic space variable in the analysis). Since ϵ^{-1} is a measure of the photon thermalization length (e.g., at an optical depth ϵ^{-1} the radiation field is "unaware" of the presence of the surface boundary and has attained the local black-body value), we see that the parameter $\tau_{min}\epsilon$ measures the location of the minimum in units of the thermalization length.

Skumanich found that if $\tau_{min}\epsilon >> 1$ (i.e., if the minimum is deeper than the thermalization distance), then only the properties of the upper layers of the chromosphere (i.e., ϵ, T_{max}), govern the properties of the emission reversal. Thus the brightness temperature of the emission peak will be T_{max} the ratio of central-to-peak intensity $\simeq\sqrt{\epsilon}$. This same conclusion was reached by J. T. Jefferies and R. N. Thomas of the National Bureau of Standards in a study which did not include variable doppler widths. However, the separation of the emission peaks, $2\Delta\lambda_s$, derived by Skumanich was found to be more sensitive to the value of ϵ than was indicated by Jefferies and Thomas. It was found that $(\Delta\lambda_s/\Delta\lambda_D)^2$ varied linearly as $\ell n\epsilon$ rather than $\ell n\sqrt{\epsilon}$. As pointed out by Jefferies and Thomas, the observed central-to-peak intensity ratio in the sun ($\simeq$0.6) rules out the applicability of this case (since $\epsilon \simeq 10^{-4}$ to 10^{-8}).

The case $\tau_{min}\epsilon < 1$ is still under analysis at the end of the year. It is evident, however, that in this case the properties of the minimum, (T_{min}, τ_{min}), enter as well as those of the upper chromosphere. One preliminary result is that the separation of the peaks is now governed dominantly by τ_{min}, and the explicit dependence is such that $(\Delta\lambda_s/\Delta\lambda_D)^2 \simeq 0.8\ell n\ \tau_{min} - 0.2\ell n\epsilon$. Analysis of intensity ratios and brightness temperatures is under way at the end of the year.

The above analysis departs from that of Jefferies and Thomas by the inclusion of variable doppler broadening. A further point of departure is to introduce a nonuniform density stratification and, consequently, a nonconstant ϵ. This is being planned for the near future. Preliminary calculations with a turbulent rather than a thermal broadening parameter have also been made. These two effects have opposite behavior, one increasing upward, the other decreasing. The assessment of the differences in the radiation field and source function have yet to be made. The above numerical work was carried out largely by Chester Ellis.

Progress in this work may be difficult, since the next step includes the introduction of an atomic level model more representative of Ca^+. Such a model increases the dimension of the equations considerably since now the subsidiary lines must be treated simultaneously.

ULTRAVIOLET RADIATION

Hiei attempted to compute the solar energy curve for wavelengths between 1500 A and 2000 A to compare with the rocket observations of Purcell, Packer, and Tousey of the Naval Research Laboratory.

For a model of the atmosphere Hiei adopted Pagel's model for the transition region and his own model of the chromosphere. The continuous absorption coefficient was estimated from the graphs of Böhm-Vitense. The metal abundances assumed by Vitense are higher than those as determined more recently by Goldberg, Müller, and Aller. Hence, Vitense's absorption coefficient of metals will be too high by at least a factor of two in the region where absorption of Mg, Si, and Ca dominates. The computation, therefore, was carried out by using both Vitense's absorption coefficient and one-half of the coefficient.

The resulting computed energy curve is higher by about 200 to 300°K than the observed one. The curve computed by using one-half of Vitense's absorption coefficient is close to the observations, and the resulting energy curve is not in disagreement with the observed curve if the photometric accuracy of the extreme UV region and the uncertainty of the continuous absorption coefficient are taken into account. If the precise absorption coefficient near 1700 A can be determined, it will be helpful in trying to fix the physical quantities at the transition region between the photosphere and the chromosphere.

WAVES IN THE CHROMOSPHERE

As a continuation of last year's work, Uchida investigated the responses of the temperature trough in the photosphere-chromosphere region (as contrasted with the higher temperature subphotospheric layer below and the corona above) to the gravitational hydrodynamic waves. By using a formulation similar to that used in last year's work but using an extremely simplified model atmosphere, he attempted to find analytical solutions for various combinations of the wave parameters (frequency and wave numbers). He found that the waves behave in a drastically different manner for different pairs of wave parameters. Especially for those wave parameters for which the vertical wavelength becomes comparable to the trough thickness, the responses are of great interest. The fundamental features here are resonances in the trapping, in the transmission, and in the reflection of the waves. Also a "tunnelling effect" of the waves through this otherwise nonpropagating layer can occur due to the "wave character" ($\lambda \ll$ typical scale of the trough). Uchida investigated the combinations of wave parameters which can yield resonant trapping of the waves and which may explain the observed oscillatory standing motion in the temperature trough in the low chromosphere. He was able to show that the trapping of internal gravity mode waves is obtained just around the frequency and horizontal wavelength of the observed oscillation.

Uchida also investigated the transmissivity of the trough for waves incident from below out to the corona above. He showed that the transmissivity for the internal gravity mode is generally low ($\sim 10^{-4}$), while that for the gravitational acoustic mode is high ($\sim 10^{-1}$), and again the resonances in transmission and the tunnel effect are conspicuous for long waves. It might be concluded, therefore, that the oscillatory velocity field in the low chromosphere is mainly the standing internal gravity wave trapped there, while the non-thermal (kinetic) energy transfer to heat the corona is due to the acoustic mode waves.

In another study, Uchida considered the problem of the effect of radiative energy exchange on the gravitational hydrodynamic waves.

Linear perturbations in gravitational acoustic and internal gravity modes were considered in an isothermal atmosphere with the effect of radiative relaxation of the locally enhanced emissivity produced by the mechanical compression of the waves themselves. The method chosen to handle the radiative term is considered to be rigorous and valid for a wide range of optical depths except when the nongray effect or the non-LTE effect comes in. Unfortunately, in the actual situation in that part of the solar atmosphere where gravitational waves are expected, these hindering effects are probably important, but it was hoped that the results would indicate the effects to be expected. The problem was solved as an initial value problem by using the Laplace transform technique. The numerical, complex arithmetic was programmed for the CDC 3600 and the height-variation and wave-parameter dependences of the real and imaginary part of the complex frequency were calculated for both gravitational acoustic and internal gravity wave modes. This work was in progress at the time Uchida returned to Japan late in the year.

Musman continued his studies of penetrative convection for the laboratory situation where the maximum density of water at 4°C is used to divide a layer of fluid into a stable and an unstable layer. Convection is then limited on one side by a stable layer, as in the astrophysical case, rather than by the physical boundary of the laboratory container. One novel feature of the system is that convection first appears in a fully developed form and smaller scale motions never occur.

STELLAR CHROMOSPHERES

In a continuation of the study of the correlation of chromospheric activity and age in main sequence stars described in last year's report, the kinematic properties of spectral types later than G5 have been analyzed by Skumanich. Preliminary results indicate that dK dwarfs (essentially G8 to K4 dwarfs, masses ~ 0.9 solar mass) with strong emission reversals in the cores of the Ca^+ resonance absorption lines

K and H (evidence of chromospheric activity) show young, Population I characteristics in agreement with those found for the dG (F5 to G5) stars. In Table 1 the results for the dG and dK stars are summarized. For comparison, extant data for dM stars, A stars, and Population II subdwarfs are included. It is apparent from the table that the dG, dK, and dM stars with strong Ca^+ emission (i.e., 'healthy' chromospheres) have kinematic characteristics significantly different from those stars with weak or zero Ca^+ emission. These stars with weak chromospheres fall intermediate between the young A stars and the old subdwarfs. Further analysis of the dK data is still in progress at the end of the year.

Table 1 -- Space Motions

Type	Number		Group speed (km/sec)		Average displacement (km/sec)		Displacement perpendicular to galactic plane (km/sec)		Population description	
	A	B	A	B	A	B	A	B	A	B
A($\leq 6^m.0$)	417	--	16	--	11	--	6	--	Normal	----
dG($\leq 8^m.1$)	42	95	22	24	19	29	12	22	Ca^+ emission	No emission
dK($\leq 9^m.3$)	39	76	22	29	24	40	14	22	Ca^+ emission	No or weak emission
dM	64	233	10	23	21	30	15	22	Ca^+ emission	No emission
F-M	--	--	--	140	--	80	--	50	----	Subdwarfs

A similar kinematic analysis for K giants indicates the Ca^+ emission intensity is not a population indicator and hence is not age correlated.

Observations of the Ca^+ line in red giant stars with dispersions of 3 to 10 A/mm (resolution ≈ 0.1 A) indicate that the Ca^+ emission reversal (K_2) and its central absorption (K_3) show violet doppler shifts with respect to the photospheric lines. This is interpreted as a mass outflow in the chromospheric layers of red giants -- in other words, a stellar wind.

In an effort to study these doppler shifts, a high resolution observational program of the red giants has been initiated by Skumanich in collaboration with A. Vaughn of Mount Wilson and Palomar Observatories. For this purpose a gas-filled Fabry-Perot interferometer is being used to achieve a resolution of 10^5 ($\Delta\lambda \simeq .03$ A). Preliminary observations have already been made on αTan (dK5) to test the system. The results look encouraging but indicate the need for a photodetector more sensitive in the UV than the one currently in use at Mount Wilson. An improvement in sensitivity by a factor of two may be achievable.

THE CORONA

CORONASCOPE II

At the present time we are still in nearly complete ignorance concerning such basic questions of coronal structure as the three-dimensional form of coronal streamers, the connection of such streamers with the more obvious surface features such as plages and extended magnetic regions, and the evolution of coronal forms as underlying activity changes. We also do not know what connection exists between structures visible in the K-corona and the magnetic fields and particle streams detected in the interplanetary medium. By and large, these problems will continue to go unanswered until the intermediate and outer corona ($1.5\ R_{\odot} \leq R < 6\ R_{\odot}$) come under more nearly continuous observation than is presently possible. A large part of our effort during the report year has been directed toward this goal of eventually securing synoptic observations of the intermediate and outer corona. Various facets of this overall program are discussed below. As with many long-term programs which have only begun to bear fruit, much of this work could be classified as "astro-engineering."

Newkirk was successful in carrying out two flights of the Coronascope II system during 1965. These flights had two goals. First, it was desired to make a balloon-borne test of the prototype of the coronagraph which we are now preparing for possible flight in a satellite. Second, the flights were scheduled so that their observations might be compared directly with those photographs made of the solar corona during the eclipse of 30 May 1965.

The first months of the year were occupied in revamping the Coronascope II system in order to improve the quality of the observations. These improvements are described in last year's report. A contract was let with the Perkin-Elmer Optical Corporation for the design and construction of a new set of secondary optics for the coronagraph, and these new optics were incorporated to yield improved angular resolution. Other modifications were made in the system to make it a realistic prototype of the satellite coronagraph. These included the use of a heat-dumping mirror surrounding the objective aperture and complete enclosure of the coronagraph from the external occulting disks to the objective lens. There was some question in our minds whether or not these two modifications, which will be essential for the satellite instrument, would introduce large amounts of scattered light into the image of the corona. The last innovation made in the system was a rather elaborate jig which allowed accurate alignment of the internal and external occulting disks of the coronagraph. Preparations for Coronascope II-α showed us that this alignment was extremely critical and difficult to perform at the operating wavelength of 0.83 μ.

The coronascope system and its crew moved to the NCAR Scientific Balloon Facility's launch station at Palestine, Texas, on 1 May 1965 to prepare the system for flight on the initial target date on 27 May. In spite of the added convenience of the "Coronaport" building in which the gondola could guide on the sun while hanging on a simulated parachute suspension, a long period of rainy weather prevented our being ready by this first target date. However, a successful flight was made on 3 June 1965 at the very end of the second target interval.

This flight, made only four days after the total solar eclipse, was operationally successful, and the coronascope system sustained little damage. A level of scattered light in the films which was somewhat higher than expected decreased their aesthetic value even though coronal streamers may still be traced out to the limit of the field at 5 $R_{\odot}$. A careful examination of these films showed that the source of the difficulty was a slightly undersized internal occulting disk. This difficulty was remedied during the preparations for the next flight.

Target date for the second flight of the series was two weeks, or one-half solar rotation, from the first. Unfortunately, the launch of this flight was attempted with rather brisk winds blowing across the launch configuration. The balloon was lost, and the gondola fell to the ground from the launch vehicle.

The last flight of the series was performed on 1 July 1965 after the coronascope system had been repaired and a new balloon purchased. The launching of this flight was also very rough. Although the apparatus continued to operate, the loss of the telemetry antenna prevented us from recording any "housekeeping" data. The shock of launch apparently also produced a slight misalignment of the optical system. Nevertheless, excellent observations of the corona, out to 5 $R_{\odot}$, were obtained.

A less successful aspect of the Coronascope II experiments has been our lack of success in quantitatively predicting the level of scattered light to be expected in the coronagraph from tests made in the laboratory with an objective lens as a synthetic "sun." The discrepancy between the laboratory measurements and the actual performance apparently is due to the fact that the laboratory source is a finite distance from the coronagraph. This unrealistic geometry has two important consequences:

1) The edge of the penumbral shadow of the external occulting disks is 3 or 4 min of arc further away from the edge of the objective aperture.

2) The radiation grazing the triple occulting disk at a particular angle is not coherent as it is with the radiation from the solar disk.

At present Newkirk and Eddy are attempting to devise a more realistic test situation in which a collimator is used to remove the "synthetic sun" to infinity without the collimator lens itself contributing scattered light.

As a result of this summer's balloon flights, we now have a sequence of observations of the intermediate corona on 30 May, 3 June, and 1 July 1965. These coronal observations, and observations of plages, prominences, K-corona, and magnetic activity, are now being studied in detail by Bohlin as part of his doctoral thesis. A preliminary examination of these observations allows identification of the same coronal streamers on 3 June and 1 July although unquestionable physical changes in these streamers had occurred during the intervening 28 days.

Comparison with the eclipse observations has proven to be somewhat more difficult because of the fact that few eclipse observers were able to photograph streamers in the corona out to as far as 5 $R_{\odot}$. We still hope that the examination of the original negatives taken by some of our colleagues on 30 May will allow the streamers in the outer regions of the corona on that date to be delineated and compared with the balloon flight observations.

We expect that the comparison of the balloon-borne observations with the nearly synoptic Koronameter coverage of the inner corona made by Hansen in Hawaii will be most productive. Already it is obvious that some of the streamers visible on the coronascope negatives can be traced down into the lower corona on the Koronameter record. Hansen's observations may well provide the key which will allow us to establish the extent in longitude and the position on the disk of the streamers.

SATELLITE CORONAGRAPH

Early in the year we negotiated a subcontract with the Ball Brothers Research Corporation (BBRC) of Boulder, Colorado, for the development of a satellite coronagraph, and this contract was approved by NASA, the primary funding agency. Under this contract BBRC carries out the design, development, and testing of the orbital coronagraph, under the direction of the principal investigators, Newkirk and Eddy, at HAO. This relationship between HAO and BBRC has proved to be a very workable one, due in part to the physical proximity of the two locations but more because of the complementary nature of the two organizations. An original constraint of the decision of HAO to enter the field of satellite experimentation was the exclusion of any permanent build-up within HAO of an engineering force necessary to design and produce a spaceborne instrument. With BBRC under contract we feel we have a first-rate engineering firm with whom we can work almost as closely as with an in-house shop. As a result of the early establishment of this working relationship with BBRC, the HAO experiment is well along in its development.

During the year the selection and preliminary testing of a photosensor for the coronagraph was completed, with a decision to adopt an image dissector tube of type similar to the International Telephone and Telegraph Corporation F4012 Vidissector. The image dissector tube is not a new development in any sense; it is essentially a simple, end-on multiplier phototube with an electronic scanning mechanism inserted between the photocathode and the dynode chain. Magnetic focus and deflection coils direct the photoelectron flux toward an aperture plate which has a single opening to the first dynode. Only photoelectrons from a single area of the photocathode are allowed to enter the dynode amplification, permitting wide versatility in scanning rate and pattern and a significant reduction in dark current. The F4012 Vidissector is a rugged, 1-in.-diameter, 12-stage tube with S-13 response. The effective size of the internal aperture in the tube is about 1.8 mils, corresponding to an angular resolution of 1/2 arc min on the coronal image. To provide a back-up in case of image-dissector failure, during the one-year anticipated lifetime of the experiment, we have decided to employ two separate image-dissector systems, each scanning a single hemisphere of the corona under normal conditions but each capable of accepting the entire image in the case of failure of the other tube. The use of two simultaneously scanned tubes also permits an increase in the speed of picture acquisition, since tubes will alternately dwell and read-out. With two tubes the orbital coronagraph should be able to secure a complete white-light coronal picture, photometrically accurate to about 5% in about 10 min. In faster modes of operation pictures of lower quality could be obtained at the telemetry limit of about 3 min per picture. Each picture will cover the corona from about 1.5 to about 6 $R_{\odot}$ with angular resolution of 0.5 arc min near the limb and about 1 arc min at the edge of the field. The decrease in angular resolution with distance from the limb is an intentionally introduced distortion to compress data.

In spite of this rapid progress in the development of the specialized coronagraph, our work has taken an unexpected and disappointing turn. During the closing weeks of 1965, NASA announced the cancellation of their effort to build the Advanced Orbiting Solar Observatory -- the satellite on which we had hoped to fly our coronagraph. In the past year we had come to understand and begun to feel at home in the satellite development field in which most of the effort goes into meeting the various "interface" problems and the scientific work seems remote and unimportant. This understanding now serves only to sharpen our disappointment, since it lets us see what a large fraction of our work till now is wasted. Even if the coronagraph eventually flies on another spacecraft, the interface problems will have to be faced anew.

Such lack of stability in planning is perhaps inevitably associated with vastly expensive work done in the public spotlight and connected with military and political goals and motives. Since we are still completely convinced that the intermediate corona needs to be observed, we have begun discussion among our staff at the close of the year on how to maintain sufficient flexibility for making progress in this complex field.

WHITE-LIGHT CORONAGRAPH FOR APOLLO

Before the cancellation of the AOSO spacecraft was announced, HAO had already decided to investigate an opportunity to place a white-light coronagraph on a proposed earth-orbiting, manned Apollo mission now scheduled for 1969. This instrument would be in most respects a duplicate of the White-Light Coronagraph Experiment which we planned for the Advanced Orbiting Solar Observatory, with two important differences. These are (1) the use of photographic instead of photoelectric recording, and (2) alignment and maintenance of the coronagraph by the astronauts who man the Apollo satellite. The proposed Apollo earth-orbit missions will last for about two weeks, permitting observations of the corona over about 1/2 solar rotation. The use of film permits much faster exposures than the photoelectric scheme used in AOSO, so that a primary mission of the proposed Apollo Coronagraph would be the acquisition of fast sequences of coronal pictures with exposures of a few seconds initiated by the Apollo astronaut at the time of limb activity. The coronagraph would be one of an array of solar instruments contained in the service module of the Apollo spacecraft, connected electrically to the command capsule for fine-guiding correction and control by the astronaut. At the end of the two-week mission the astronaut would remove the film from the experiments, abandon the service module, and return to earth. Initial studies of this coronagraph were under way at the end of the year, and, with the cancellation of AOSO, may represent our only opportunity to fly an instrument before the 1970s.

SYNOPTIC CORONAGRAPH

Although the satellite coronagraph may well represent the ultimate instrument for producing synoptic observations of the outer corona, the vagaries which affect satellite instruments suggest that we should attempt to gather these observations by as many different techniques as possible. At the end of the report year Newkirk was investigating not only other satellites which might carry our coronagraph but also aircraft, balloon, and ground-based observations. The goal is to be able to observe the corona out to at least 5 $R_\odot$ on a nearly daily basis. Several possibilities suggest themselves, and we have begun investigation to be able to pick the optimum technique:

1) The feasibility of balloon-borne coronagraphs has already been demonstrated. However, our experience with Coronascope II raises some doubt that it can be used on anything like a daily basis. This doubt comes about because of the logistic problems and inevitable repair jobs which must follow each flight. Nevertheless, the feasibility of a small, lightweight, balloon-borne coronagraph must be investigated.

2) Aircraft of the U-2 or X-15 variety are capable of flying at altitudes up to 30 km on a regular schedule. A coronagraph mounted on such a vehicle could easily observe the corona in a manner similar to

Coronascope II and would have the advantage that it need not be repaired and completely readjusted after each flight. Even though the operational costs would be high, a schedule involving a flight every few days might be feasible.

3) The possibility also exists that ordinary jet aircraft flying at altitudes of 12 to 14 km could carry a Koronameter which, at that altitude, might well be able to detect the corona as satisfactorily as the more expensive high-altitude coronagraphs.

4) There is good evidence that the performance of the present Koronameter can be improved in several fundamental ways. The best complement to the satellite coronagraph may be a super Koronameter which is capable of extracting the extremely minute coronal signals out of the background of sky radiation. This instrument must be designed with the greatest care so that the erroneous signals produced by varying sky brightness and polarization, varying extinction, and instrumental polarization can be measured simultaneously with the primary signal. A preliminary investigation of the feasibility of such an instrument is extremely encouraging.

KORONAMETER

Under the original agreement with the University of Hawaii for collaborative studies of the white-light corona, the Koronameter was to be operated at the University's Mees Solar Laboratory on Mount Haleakala for the International Quiet Sun Years, 1964-1965. The success of the observing program there during the past two years has exceeded our expectations, with observations of the innermost corona being made by Hansen and Garcia on some two-thirds of the days. These data provide a remarkably complete documentation of the behavior of the white-light corona during the uncomplicated (minimum) phase of the solar cycle, from which we shall better understand the morphology of the coronal enhancements, particularly as related to the other solar phenomena such as filamentary prominences and plages.

Most of the Koronameter observations at scanning heights of 100,000 and 200,000 km above the solar limb for the years 1964 and 1965 have now been reduced to absolute intensities, related to the brightness of the solar disk, by Shirley Hansen of the University of Hawaii (now at HAO), with assistance during the summer from two recent high school graduates on Maui, Jon Okada and Ronald Kwon (now students at the California Institute of Technology and at Harvard, respectively, as National Merit Scholars). A third student, Michael Perry (also a National Merit Scholar, at the University of Chicago) began calculations to conveniently transform the observed positions of coronal features to the actual solar longitude and latitude, taking account of the sun's axial tilt (P and B_o) and assuming several alternative electron density models. This exact transformation is necessary before a meaningful comparison can be made of coronal enhancements and underlying chromospheric phenomena.

It is also necessary to determine the rotation period of the corona as a function of latitude. Actually this is an interesting research problem in itself, because there is reason to expect that due to interactions with extended magnetic fields, as well as the solar wind, the corona may rotate at a different rate from the sun itself. In collaboration with Harold Loomis of the University of Hawaii, the Hansens are exposing the Koronameter data to a spectral power series analysis. This work is still in the preliminary stages of key-punching, and also awaits the reduction of data for the final months of 1965.

Our experience at Haleakala demonstrates the need for continuing these ground-based studies of the corona from a location with suitably clear skies and especially at low latitude where the sun's average zenith distance is small, and hence where the potential errors introduced into our polarimetric measurements by the polarized Rayleigh sky will not be serious. In some respects, Haleakala has not been found to be the optimum location for this extremely sensitive program. The very convenience of the site, with a paved road and commercial electrical power right to the summit, has led to the rapid development of a dense clustering of astronomical, atmospheric, satellite tracking, and communications facilities (a so-called "Science City") with consequent degradation of the cleanliness of the atmosphere. A still more serious source of interference has been swarms of insects (particularly of genus Nysius), that congregate just above the summit on warm, windless days. While most frequent during the late summer and early fall (July through October), these swarms have occurred in all months of the year and, at times, were so numerous that observations with the Koronameter were completely impossible. In late 1963 we turned to John Beardsley of the Hawaiian Entomological Society for help with this problem and, after more than a year of laboratory and field studies, he concluded that the breeding areas for the Nysius are in widely scattered range and farmland far below the summit and that the insects are probably brought to the top by daily convective updrafts. Thus complete elimination of the population by extensive spraying with insecticide seems impractical, although we found that the interference could be somewhat reduced by coating the bushes within a radius of about one-quarter of a mile from the observatory with DDT powder.

For these reasons, investigations were begun in the fall of 1964 to see if the other high mountains in Hawaii (Mauna Kea and Mauna Loa on the Big Island) might offer a more suitable site for the Koronameter work. Mauna Kea is a dormant volcano and has an interesting network of roads along the slopes, used by hunters, which provide relatively easy access to vast areas of undeveloped land. During the summer it is possible to drive to above 13,500 ft on Mauna Kea to a small astronomical dome which was built by Gerard Kuiper of the University of Arizona for studies of the site as a possible location of a large, nighttime telescope. However, field investigations soon showed that for our specific purposes, Mauna Kea might be less suitable than Haleakala because of semiarid vegetation extending to 11,000 ft, resulting in a high insect population as well as seeds and pollen -- all contributing aerosols to the atmosphere and a bright aureole around the sun.

Mauna Loa, on the other hand, is still an intermittently active volcano, and its slopes from the summit down to about 8,000 ft are a barren wasteland of broken lava completely devoid of vegetation. Furthermore, since relatively little of this fresh lava has been broken down into soil by wind and rain erosion (in contrast to the much older volcano, Mauna Kea) there is little atmospheric contamination due to naturally blowing dust. And finally, using meteorological observations from the Weather Bureau's station at 11,150 ft on the north slope of Mauna Loa, it was possible to compare the amount of cloudiness above Mauna Loa with that at the Haleakala summit. This study, carried out jointly with Saul Price, the ESSA Regional Climatologist, indicates that there is at least as much potential observing time, free of clouds, on Mauna Loa as on Haleakala.

In order to continue the Koronameter program after the IQSY, a small telescope enclosure, using a prefabricated 16½-ft Ash Dome, was built at the Weather Bureau's site at Mauna Loa late in the year. The Koronameter was moved from Haleakala and mounted on HAO's 10-ft equatorial table at Mauna Loa early in December. The first observations at this new site were made by Hansen and Garcia on 12 December.

1965 ECLIPSE - 1966 ECLIPSE

Malville and Eddy succeeded in measuring the strength and polarization of the 10747-A emission line of Fe XIII at the 30 May 1965 eclipse from the island Bellingshausen in the South Pacific. Hultquist provided instrumental assistance both in Boulder and on the island. The properties of the line were measured using a 10-in. telescope fitted with a photoelectric photometer using a tilting interference filter for wavelength information. A single radial scan was secured from the limb of the sun to about 2/3 $R_\odot$ above the limb. An attempted, simultaneous measurement of the 3388-A line of the same ion was not successful, except in the innermost corona. A preliminary analysis of the observations indicates that the 10747-A line is polarized linearly and the polarization is about 18% at 1.7 $R_\odot$, decreasing to zero at the limb.

The sense of polarization is with E vector perpendicular to the limb. A thin covering of cirrus at the time of totality casts some doubt on the measurements, but the measured polarization was less than anticipated on the basis of purely radiative excitation of the Fe XIII ion. The measured small linear polarization can be accounted for by a large collisional cross-section of the ion, together with some depolarization due to line-of-sight integration through the corona. Eddy and Malville intend to repeat their measurement of the strengths and polarizations of the emission lines of Fe XIII at the eclipse of 12 November 1966, which traverses the South American continent from Lima to north of Buenos Aires. The 1966 eclipse observations are planned to be made from a high-altitude aircraft with a gyro-stabilized platform similar to that developed by Dunn at Sacramento Peak Observatory for the 1965 eclipse.

In a related study, Charles Hyder of UCLA and Warwick collaborated in preparing a discussion of resonance polarization in solar magnetic fields. Earlier, they had discussed the quantum mechanical computation of the rotation and depolarization effects when a weak homogeneous field is present in the scattering region. The measure of the effectiveness of the field in modifying polarization conditions is the Lamor frequency divided by the spontaneous transition rate out of the upper atomic level involved in the scattering. The new development is concerned with replacing the quantum mechanical calculation of rotation and depolarization, which is quite complicated, with a semiclassical calculation. That this might be possible is clear from the fact that classically the effect has already been analyzed, with the correct quantum mechanical result, for a line with the normal triplet pattern. Hyder and Warwick have now extended the method to anomalous patterns.

THE CORONAL LINE PROFILE

The study of line-profile shapes has been continued by Donald Billings, of the University of Colorado, and Lilliequist. Most of their attention has been directed toward analyzing a set of 72 consecutive red-line spectrograms, each exposed at the same elevation in the same coronal condensation for 70 sec. Lilliequist traced and digitized these spectrograms with the Sacramento Peak microphotometer-digitizer, then with the NCAR CDC 3600 he analyzed the shape of the red and violet halves of each profile for systematic deviations from the best fitting gaussian, where shoulder enhancement was arbitrarily called a positive deviation and wing enhancement a negative deviation. Before proceeding further, he made a special study to determine the shape of the instrumental profile and the extent to which it would distort incoming gaussian-line profiles. He found a definite asymmetry in the instrumental profile that would have quite a significant effect on the metal lines of prominences, but he also found that coronal-line profiles were too wide, compared to the instrumental profile width, to have their shape distorted by this instrument. The uncertainty, arising from photographic graininess, in assigning a value to the continuum intensity was the greatest single source of error in this analysis. Allowing for a maximum reasonable variation in the values chosen for the continuum, one could still distinguish significant quasi-periodic fluctuations in the shape deviations as a function of time. On the average for this set of spectrograms, the red half of the profile had a positive deviation, and the violet half had a negative deviation. As time elapsed during these observations and the amount of deviation of each half-profile changed, the absolute values of difference between the deviation of each half-profile from gaussian seemed to remain nearly constant; i.e., an increased positive deviation of the red half accompanied a diminished negative deviation of the violet half. A power spectrum analysis of the deviations of the red versus the violet halves of the profiles revealed strong coherences at a period of 226 $\pm$ 35 sec and 528 $\pm$ 35 sec. A power-spectrum analysis of the shift of the entire profile from the mean position of all the profiles was made by Jo Ann Joselyn of the University of Colorado. This spectrum was correlated with the deviation of the red halves and yielded a strong coherence at a period of 453 $\pm$ 35 sec.

Billings has suggested that the positive deviations are associated with coherent motion of the radiating ions, such as harmonic oscillation or angularly symmetric flow over a circular cross-section whose plane includes the line of sight. In general, negative and positive deviations cancel each other to a certain extent, and one probably observes only the net deviation. These spectrograms show evidence of a combination of a temperature distribution in the line of sight and a type of coherent mass motion that contributes more distortion to the red than the violet halves of the profiles. A cylindrical or conical structure whose axis is not perpendicular to the line of sight and which has a linear axial temperature gradient would be sufficient to provide the temperature distribution effect. And waves or shock fronts, traversing the length of such a structure, as suggested by Billings, would provide the coherent motion distortion.

To interpret observational data of the spectrum of the solar corona it is necessary to solve the equations of statistical equilibrium. These equations include various atomic rate processes. In particular, the only important mechanism by which ions are destroyed to form more highly ionized systems is by ionization by electron impact. Ionization cross-sections have been calculated in various approximations by Rudge, in collaboration with S. B. Schwartz of the Martin Company. A comparison of various theoretical procedures was first made for the calculation of ionization cross-sections in the hydrogen isoelectronic sequence. Recent theoretical work by Rudge and Seaton had indicated a number of theoretical advances, and experimental data were available for the cases of ionization of hydrogen and He^+ from their ground states. Simple formulas have been derived which provide fits to the cross-sections and to the reaction rates.

SOLAR ACTIVITY

THE K/H PROBLEM

Last year's report described a study of the resonance doublet lines of Ca II, Sr II, and Ba II; these lines were referred to as the K and H lines. Tandberg-Hanssen found that the ratio between the intensities of the K line and the H line of Ba II is abnormally high in the middle chromosphere, while the corresponding ratios for Ca II and Sr II are correctly predicted by theory. Indications were also found that the K/H intensity ratios for Sr II and Ca II are quite small in some prominences, but it was felt that this might be due to an inadequate correction for self-absorption. In the attempt to solve these problems, an analysis of Climax observations of the spectra of prominences was continued through part of the report period. A number of exceptionally good spectra were singled out and the following conclusions are based on them.

Barium

1) The mean excitation temperature corresponding to the K/H intensity ratio is 5900°K.

2) The broadening of the K and H lines is almost entirely due to large-scale mass motions ("turbulence"), and corresponds to a mean broadening velocity of 8 km/s, ranging from 6.6 to 9.5 km/s in individual cases.

3) No convincing case has been found in which the K/H intensity ratio has exceeded the theoretical upper limit of about 2.60, as it does in the chromosphere.

Strontium

1) The K and H lines yield results in good agreement with the barium lines. The mean excitation temperature is 5300°K.

2) The broadening velocity ranges from 6.6 to 11.0 km/s.

3) Indications of self-absorption have been found in the K line in very dense prominences, but generally the line profiles are gaussian. In some prominences the core is narrower than gaussian, giving the profile a more triangular shape.

Calcium

1) The K and H lines are self-absorbed in all dense prominences. In the more tenuous parts of such prominences and in many small and faint prominences the lines are nearly gaussian. Also, here the "nearly gaussian" profiles often seem to have a more triangular shape.

2) The broadening velocities are virtually the same as for Ba II and Sr II.

3) The excitation temperature is less reliably determined for Ca II than for Sr II and Ba II (due to the closeness of the $4^2P_{3/2}$ and $4^2P_{1/2}$ levels) but seems to be very similar to the values found for Ba II.

Tandberg-Hanssen has also studied the influence on the line profile of a source function varying with optical depth in the prominence. It turns out that a gaussian profile can be reproduced by a source function decreasing with depth and triangular-shaped profiles may also be constructed with such a source function. In the past it has been concluded that a gaussian profile may indicate a constant source function. This study shows that one should be careful not to draw conclusions that are too sweeping regarding the source function from the observation of a gaussian profile. Also, the optical depths deduced from self-absorbed profiles under the assumption of a constant source function are considerably greater than the optical depths deduced from a source function varying with depth.

HELIUM LINES IN FLARES AND PROMINENCES

Tandberg-Hanssen continued his study of the excitation of helium in flares and prominences. This program was initiated during the previous report period, and the first part of the study has now been brought to an end.

The ratio between corresponding lines of the triplet and of the singlet series of He I is close to 3 when the lines are formed under LTE conditions. One facet of the first part of this study was to see how the ratio varies in prominences of different degrees of activity.

The main conclusions are:

1) The triplet/singlet intensity ratio, as measured by the lines 4471 A and 4922 A, increases from a value close to 3 in very active surge prominences to values approaching 30 in quiescent prominences. Nearly all intermediate values are found in prominences showing different degrees of activity.

2) These results are substantiated by using the hitherto unobserved ratio between the lines 5876 A and 6678 A. No very active prominence was observed in these lines, but we obtained values for the intensity ratio ranging from 6 in semiactive prominences to 25 in very quiescent ones. As indicated by the second part of the program, this behavior may partly be explained as due to the increased importance of collisional excitation as one goes to denser and more active objects in the solar atmosphere.

3) Within the triplet structure we have studied the $n^3D \rightarrow n^3P$ and the $n^3S \rightarrow n^3P$ transitions. Using the lines 4471 A and 4713 A, we find for the intensity ratio 4471/4713 values ranging from about 4 to more than 20, with a tendency for active prominences to show the smaller values. The very small values tentatively reported by Zirin and Tandberg-Hanssen some time ago are probably not real.

4) Conclusion 3 has been verified using the lines 4026 A and 4121 A; their ratio yields results nearly identical with those from 4471 A and 4713 A. The second part of the program was under way at the end of the year. It consists in determining the importance of collisional excitation and the effect of optical depth on the observed intensity ratio. Tandberg-Hanssen hopes to solve the statistical equilibrium equations using the best available data on cross-sections supplied by Rudge.

SOLAR MAGNETIC FIELDS

Malville initiated a study at Climax of the relationship between the spectra and magnetic fields of quiescent prominences. Using the 5-in. coronagraph, spectra in several wavelength regions were obtained of practically all the prominences observed with the H-α magnetograph attached to the 16-in. coronagraph. Lines of hydrogen, helium, and metals are measurable on all the graded height sequences and are being used to relate the excitation conditions in the prominence with each of the measurements of magnetic field. Spectral features that are being used for the study are the following: 5876 A, 4471 A, 4713 A, 3889 A, 4078 A, Sr II 4026 A, He II 4686 (when present), high members of the Balmer series, and the Balmer continuum. The concurrent magnetic field measurements were made by Rust. At the end of the report year the spectrograms were being measured.

Recently Hermann Schmidt of the Max-Planck-Institute für Astrophysik has shown that before, during, and after solar flares there occur large changes of the total magnetic flux in the local solar atmosphere. The geometrical configurations in the active regions show few significant changes, however. Since the electrical conductivity is extremely large in the solar atmosphere, the implication was that the observed rapid changes in the total flux must arise from the upward convection of subphotospheric fields into the solar atmosphere. It is unlikely, however, that such convection would leave the existing field configurations unchanged. These conclusions assume that conductivity is everywhere large and uniform. It is well known, however, that the electrical conductivity which is proportional to $T^{3/2}$ changes rapidly in regions of large temperature gradients, such as in the vicinity of sunspots, prominences, spicules, and the chromosphere-corona boundary. A gradient in electrical conductivity may, under suitable conditions, give rise to considerable changes in the total flux of the local solar atmosphere without affecting existing geometric configurations to any great extent.

Altschuler pointed out the importance of the gradient of the conductivity and began a study of its effects. He is treating thermodynamic instabilities and hydromagnetic effects in a self-consistent manner. Although conditions are extremely difficult, he is investigating the effect on Jupiter's radio emission of stable discontinuities in electrical conductivity which may exist at the top of Jupiter's atmosphere.

SOLAR RADIO BURSTS

During the fall, Malville undertook to analyze high speed records of meter wave solar radio bursts obtained at the University of Michigan. The excellent time resolution of these records allowed the determination of rise and decay times of very short duration bursts superimposed on Type IV continuum. These bursts have distinctly shorter durations than the normal metric noise storm bursts and, in contrast to the noise storm bursts, appear to be adequately interpreted in terms of collisional damping of plasma oscillations. The observed mean decay time at 345 Mc of 5.5×10^{-2} sec indicates a coronal temperature of 2.2×10^{6} °K. Observed increases of the decay times suggest the occurrence of occasional short-lived and local increases of the coronal temperature. Analysis of the distribution of decay times indicates that no more than 4% of the bursts could occur in the second harmonic, the majority occurring in fundamental mode.

In collaboration with Ted Hartz of the Canadian Defense Research Telecommunications Establishment, Warwick was able to establish the consistent identification of solar Type III (fast drift) radio bursts down to 1.2 Mc. The low-frequency data came from the Canadian "topside sounder," Alouette, and were contemporary with Type IIIs observed in Boulder from 20 to 41 Mc. They studied the persistence of the emission as a function of frequency, and established that it is reasonable to interpret the decay of the emission in terms of the environmental coronal electron temperature. Since the radio frequency of the burst represents the electron density, in effect we have a means for establishing coronal temperatures at extremely high elevations, as much as 10 R_{θ} from the sun, and clearly in the regions of space occupied by coronal streamers.

These data support the contention that the Type III phenomenon is essentially a low-frequency effect, and suggest that a search be made for the bursts down to the lowest frequencies (about 100 kc) nominally expected to penetrate the interplanetary plasma. These data are also consistent in a general way with the coronal model devised by Chapman from Blackwell's South American data on the white-light corona.

One consequence of this interpretation of Type III burst persistence as a temperature effect (e.g., long durations imply high temperatures) is that the "continuum" observed to follow Type IIIs (called "Type V") may itself be generated in extremely hot coronal regions created in the wake of strong or repeated Type III bursts. A subsequent stream of fast particles, similar to those producing ordinary Type IIIs, excites a corona superheated by the earlier particles; the emission that results endures for a minute or two instead of decaying within a few seconds (at 20 or 30 Mc). A detailed study of published Type V records reveals many bursts that are consistent with this hypothesis.

The corona may normally receive its energy from other processes than this fast particle heating mechanism; the superheated corona following a Type III particle stream cools within ten minutes back to the preburst condition. However, at times of decametric continuum Type IIIs occur so frequently that we suggest they are then likely to be a major source of corona heating in active centers.

A problem arises in any study of solar radio bursts. Observations of the variation of burst intensity in time and space and of the frequency distribution of the burst radiation should yield important information regarding the mechanism of radio noise generation, and should provide clues to the local coronal conditions and possibly to the mechanism of particle acceleration. To extract this information from the observations, however, it is necessary to have an adequate theory of the interaction of plasma and radiation. Elementary theories have provided important qualitative guidelines regarding the mechanisms of these bursts, and have shown considerable success for the case of the fast drift (Type III) burst. There has been considerable progress in recent years in the formulation of sophisticated equations governing the interaction of plasmas and radiation and in the application of these equations to solar burst models. These new approaches, however, are complicated, and are not yet integrated into the toolbox of solar physicists.

Altschuler has, therefore, undertaken to disseminate these theories in a less abstruse form so that they will be useful to solar physicists. At the end of the year he had begun the preparation of a set of lectures on this topic.

FLARE PREDICTION

Firor and Lilliequist have continued their evaluation of flare prediction schemes. Their study of the "skill" of two solar physicists who have been issuing forecasts of solar activity up to four weeks in advance was brought up to date during the summer. During the first half of 1965, as solar activity increased sporadically from the levels of 1964, the skill demonstrated by one forecaster decreased substantially while that of the other increased very slightly, and the accuracy of forecasts based on a strict 27-day recurrence and random selection from the yearly average distribution of activity generally decreased until all four sources of forecasts showed about 50% success, with the solar physicists having a few percentage points lead over the strictly mechanical means of forecasting.

THE SOLAR SYSTEM

JUPITER AURORA

The nature of decametric radio emission from Jupiter and the known properties of its magnetic field suggest that trapped, energetic (10-kev) electrons frequently impinge on its upper atmosphere. These events, occurring at the time of decametric emission, could ionize atmospheric constituents and cause a visible recombination spectrum. This Jupiter auroral emission has long been suspected but never observed. Past attempts to observe the effect in H-α have largely used filter monochromators, with bandpass 15 to 20 A, or low dispersion spectrographs. These early efforts were in the form of patrols, as the time and place of suspected emission was not known, and the best previous search was limited to auroras brighter than 100 kilorayleighs, none of which were observed.

The recent finding that Jupiter's satellite Io controls much of the radio emission makes it possible to predict the time and locus of probable auroras on Jupiter and thus greatly increases the chance of detection. Auroral activity is likely to occur on magnetic field lines connecting Io to Jupiter, at times and places favorable for detection several times per week, with duration of 3 to 5 hr per event. Eddy and George A. Dulk, of the University of Colorado, who did much of the work on the Io correlation, have re-initiated the optical search for these events. In August they were allowed to use the photoelectric scanner on the large coronagraph-spectrograph at Sacramento Peak Observatory. In November and December they continued the search with higher resolution using the Coudé spectrograph at the 84-in. telescope at the Kitt Peak National Observatory. Auroral emission expected is a narrow, weak perturbation or asymmetry in certain of the reflected solar absorption lines, doppler-shifted from line center by planetary rotation. With spectral resolution of about 0.1 A and dispersion 4 A/mm a 1.2 kilorayleigh aurora should be detectable in H-α, and approximately 10 kilorayleigh auroras elsewhere in the spectrum. Early analysis of the plates made at Kitt Peak shows no evidence of these effects.

COMET

Slit and slitless spectrograms of the sun-grazing comet, Ikeya-Seki, were obtained by Malville with the 5-in. coronagraph during the afternoon of October 20, just before perihelion passage. The most interesting aspect of the spectrograms is the detection of a marked variation of the sodium, D_2/D_1 ratio across the comet and in time. The ratio in the head approached unity as the comet approached the sun, falling from 1.7 at 2100 UT to 1.2 at sunset, 2230 UT. Moreover, the ratio increased to a value of about 2 in the tail. This behavior is interpreted as an optical depth effect and may allow us to determine for the first time the variation of atomic densities in the head and tail of the comet. The comet nucleus was traveling in excess of 100 km/sec away from the earth at the time of observations, and the sodium lines in the head showed a redward doppler shift of 2.4 A; a peculiar aspect of the spectra is that the Fraunhofer spectrum scattered by the dust particles in the head showed a blueward shift of 1.4 A. It would appear that the dust is flowing away from the head faster than the gas; a possible interpretation of this anomaly is that the sodium is carried away from the nucleus on fairly massive particles, showing more resistance to a solar repulsive force, corpuscular or radiative, than the smaller dust particles responsible for the scattered continuum in the head.

THE UPPER ATMOSPHERE

GEOMAGNETISM AND THE IONOSPHERE

During 1965 Matsushita completed a study of the geomagnetic solar quiet daily variation field, Sq, and the responsible current systems for three longitudinal zones during each of three seasons using IGY data obtained at 69 stations. This may be the first time that the current system has been shown in such detail. He also completed a study of the geomagnetic lunar daily variation field, L, and the responsible current systems in each season. A reasonable internal L current system and global expression of the external L current system were presented for the first time.

Matsushita also studied ionospheric perturbations and their influence on geomagnetic pulsations. In preparation for geomagnetic observations in Peru during the solar eclipse to take place on 12 November 1966, he prepared a summary of solar eclipse effects on the geomagnetic field.

Cole compared the dissipation of energy in the auroral electrojet with that in the stable auroral red arc which he considers to be a major sink of energy for the ring current during magnetic storms. It was found in the face of considerable observational uncertainties that the former is comparable to, and probably exceeds, the latter. This is consistent with his previous finding that high latitude electrodynamic processes associated with normal aurora produce a ring current in the geomagnetic field.

With R. B. Norton of ESSA, Cole critically examined the sporadic E problem. They observed that there is a factor of ten difference between the upper limit of the value of the recombination coefficient allowable by wind-shear theory and the larger value used by other ionospheric workers whose value is similar to, but inferred independently of, that provided by laboratory measurements. This gulf would be smaller if the electron temperature in sporadic E clouds were sufficiently high, as measurements sometimes indicate. However, this introduces a serious problem of the source of energy for the electrons. Cole and Norton found that heat conduction in the electron gas from the F-region and local joule dissipation of likely electric current were inadequate sources of heat for the electrons. They note that the wind-shear theory does not appear capable of explaining the magnetic variations associated with sporadic E.

In cooperation with Matsushita and W. H. Campbell of ESSA, Saito studied some generation mechanisms for geomagnetic micropulsations. To interpret the dawn-dusk asymmetry of the pulsation signal characteristics, the unique auroral latitude enhancements and the observed distribution of the high energetic trapped particles, a three-dimensional deformation of the earth's magnetosphere has been investigated. The pulsation activity associated with the solar wind was applied to a study of the solar M-region behavior.

Cooperating with Campbell and his staff, Saito has succeeded in obtaining daily dynamic spectra of the pulsations for the frequencies from 4 to 0.002 c, covering all seven categories of pulsations. He is trying to investigate some source mechanisms for the pulsations by means of these dynamic spectra, based on the magnetic tape data obtained at a world distribution of ESSA stations.

Chapman continued his studies on the morphology and theory of magnetic storms and auroras in collaboration with S.-I. Akasofu of the University of Alaska. The work on the magnetic field of a symmetrical ring current, described in last year's report, was continued by Chapman, Kendall, and Akasofu, and Swartztrauber. The work of expressing the ring current field in terms of spherical harmonic functions was nearly completed when Kendall noted an error in the earlier work on the ring current by Akasofu and Chapman. At the end of the year Kendall is computing the necessary numerical corrections.

OZONE

As discussed in last year's report, analysis of the photochemistry of ozone in an oxygen atmosphere shows that, at heights above 50 km in the earth's atmosphere, large diurnal variations of ozone are to be expected. London extended this problem to study possible changes in ozone and atomic oxygen concentrations resulting from varied changes in the available solar radiation associated with solar activity, or the occurrence of a solar eclipse. In particular, the variations in total ozone during a solar eclipse at low latitudes were investigated in preparation for analysis of the data of the forthcoming eclipse across South American on 12 November 1966. At the time of a solar eclipse the cut-off of solar radiation results in an immediate increase of ozone. (The kinetic recombination processes involving atomic and molecular oxygen and ozone tend to produce ozone, while the ozone dissociating solar UV has been temporarily elminated.) This effect is most pronounced at levels of about 70 to 80 km. At lower levels (i.e., below 40 km), because of the depletion of solar radiation, the change in ozone concentration is quite small. Since the maximum ozone concentration is generally found at about 25 to 30 km, the calculations show that the increase in total ozone, as observed at ground from second contact to shortly after third contact, should be of the order of 1%. This is barely observable with the available instruments at, for example, Huancayo, Peru.

LABORATORY STUDIES

VACUUM UV SPECTROSCOPY

The theta-pinch plasma machine, briefly described in the previous report, has been put into operation by House as a light source for the production of radiation from highly ionized coronal-type ions. The emission lines from impurity elements added to the plasma can be observed in the vacuum UV and x-ray regions of the spectrum, a range from about 10 to 1100 A. The goal of this experiment is to supply new atomic-energy-level data to help complete the identification of unknown lines in the rocket spectrum of the corona.

The light source may be briefly described as an electrodeless, theta pinch discharge powered by a 45-kilojoule, 20-kv, energy-storage capacitor bank. When the bank is discharged a current of 1.5 Ma flows through a single turn coil. Inserted into this coil is a ceramic discharge tube through which flows a mixture of hydrogen at a pressure of 50 μ, along with 3 to 5 μ of the impurity gas whose spectrum is to be analyzed. The current through the coil produces an axial magnetic field of about 80 kG which compresses and heats the plasma to 200 to 300 ev.

Two operational characteristics of this machine are of prime importance in the production of coronal-type spectra. First, a relatively high-purity plasma has been attained. It is particularly helpful in the analysis of the spectra to know that the level of intrinsic impurity is low enough so as not to dominate the spectra and thereby overwhelm or interfere with the spectra of impurities intentionally added for analysis. In our previous work on a higher energy plasma source at Los Alamos the ever-present, strong, background spectrum presented difficulties in analysis which we are now able to avoid.

The second feature of the machine which is of major importance is that it exceeds the efficiency of the initial design estimates. It has been established through a measurement of the inductance of the circuit components that 82% of the energy stored in the capacitors is transferred to the coil. This is a high efficiency for this size and

and type of machine, and it is attained through minimizing the stray inductance in the circuit. The stray inductance of the system excluding the coil is 5.7 nanohenries, while the inductance of the coil is 25.9 nanohenries.

After the machine was completed, debugged, and tested, initial data were taken which proved productive. Some of these will be described below. Following this period of initial operation, manufacturer's errors in the main components of the system (capacitors and ignition switches), became evident, and these components were replaced, which caused a significant down-time. As the report year draws to a close, the system is being readied for a new start-up. When we resume operation, we are prepared to carry out some of the diagnostic experiments to establish the physical properties of the plasma, and to continue on the main goal of the program, which is production and analysis of highly ionized spectra.

Several of the diagnostic tools which were described in the previous report have either been constructed or are still in the shop. A two-channel continuum x-ray monitor has been built and calibrated by Blake. This instrument will be used to determine the temperature of the plasma through a measurement of the bremsstrahlung emission curve below 20 A. Two instruments to be utilized for the electron-density measurement are under construction by Wagner. The first is a Fabry-Perot laser interferometer in which the fringe shift produced by a laser beam traversing the plasma is measured and, through the index of refraction, related to the electron density. Another apparatus being constructed for electron-density measurement involves the determination of the absolute intensity of the continuum in the visible region of the spectrum. This measurement, coupled with an independent measurement of of the temperature, will yield electron density. In addition to these diagnostic tools, the neutron monitor and x-ray survey camera described in last year's report have been built by Blake. The x-ray spectrometer which was also described in some detail in last year's report is still under construction. This instrument will be used to observe the emission lines in the wavelength range below 100 A, thus giving a complete coverage of the spectrum from approximately 10 to 1100 A when used in conjunction with the vacuum UV spectrograph.

During the initial period of operation of the theta-pinch plasma machine, the diagnostics in use included a single-frame image converter camera and an x-ray pinhole camera. With the image-converter photographs we were able to observe the compression of the plasma and the onset of any instabilities which disrupt the confinement, or any drifts which force the plasma toward the containing wall. The x-ray pinhole pictures of the plasma, which had to be accumulated over many discharges, showed a stable, well defined, symmetric emitting volume on the axis of the discharge tube.

The new data obtained by Deutschman with the Hinteregger vacuum spectrograph fill some of the gaps in isoelectronic sequences which end on coronal-type calcium ions. Specifically, 30 new lines in the spectrum of S IX and X and Cl IX, X and XI have been identified. These lines are inner-shell resonance lines between configurations $2s^2 2p^n$ - $2s2p^{n+1}$ where n = 3, 4 and 5. The same transitions in Ar X, XI, and XII have also produced an additional 15 lines. These lines of argon were just recently reported in the literature. All of our internal consistency checks lead us to believe that we have more accurate wavelengths on these argon lines. In addition to the above, five new lines in the sodium-like spectrum of Cl VII were discovered originating on higher principal quantum number levels previously observed.

The new energy levels up through the spectrum of argon allow improved extrapolations for the ground-term splittings of Ca XII, XIII, and XIV. However, by improving the heating in the plasma we hope to be able to measure directly the ground-term splittings of these ions. In the spectra produced so far Ar XII, with an ionization potential of 539 ev, represents the highest ionization yet observed in our plasma source. If we are to produce, say Ca XIV with an ionization potential of 727 ev, then we must increase the temperature of the plasma. Two improvements will be made to the theta pinch which we hope will increase the heating.

First, the energy of the preionization bank is being increased. This preionization bank is discharged and allowed to ring out before the main 45-kilojoule bank is fired. The purpose of this is to produce initially a highly ionized plasma so the energy of the main bank will be put to most effective use, so that the energy will be used in heating the plasma rather than ionizing the hydrogen. The energy in this new preionization bank is 2800 joules at 20 kv compared to the 400 joules used previously. Second, we will also add a reverse bias capacitor bank. This system will be discharged before both the preionization and the main bank. Here the purpose is to insert a magnetic field into the plasma in reverse polarity to the field produced by the main bank. The magnitude of the magnetic field in the reverse bias bank will be of the order of 2 to 8 kG compared to the 80 kG of the main bank. The presence of the reverse bias field has been proved to increase the final heating through the incompletely explained phenomenon of annihilation of magnetic field lines.

In our work so far we have developed the view that the best way to analyze the spectra is to start in an isoelectronic sequence of astrophysical interest at the point where the accumulated data cease to exist. From there we attempt to extend the sequence experimentally step by step. This is in contrast to the usual technique of extending the data by theoretical extrapolations, which are frequently proven to be greatly in error. With the theta pinch and the high-voltage spark source described in previous reports we have a sufficient range of energy available to produce a wide range in ionization. Most important, these sources appear to be ideally suited to generate spectra similar to that of the corona. These spectra are needed to fill the gaps in data in Charlotte Moore's tables of atomic energy levels.

In conjunction with the experimental work the theoretical program based on a Hartree-Fock computer calculation has begun. Davies-Jones is carrying out this work. The goal is to provide purely theoretical energy-level calculations that can be compared with the experimental results.

SHOCK-TUBE STUDIES

Shock-tube studies of relaxation phenomena under non-LTE conditions have been undertaken to provide ground work for examination of astrophysical problems of particular interest, such as solar flares, spicules, and others. An electromagnetic shock tube has been assembled by Nakagawa for such a purpose, and shock velocities of the order of 30 to 50 km/sec have been attained. However, poor reproducibility of the apparatus has prevented the progress of the systematic study of the relaxation phenomena. Various improvements have been tested, and the work along this line will be continued. The development of diagnostic techniques and tools needed for the present study has also been undertaken and is currently in progress.

The physical quantities of importance in the study are the velocities, temperatures, and densities of the constituent gases, namely electrons, ions, and atoms. It is therefore desirable to determine these variables independently. The velocity of shock waves represents closely the velocity of ions and atoms, which can be measured by means of a pressure probe (a piezoelectric device to record pressure jump across the shock front). Then the temperature and density of electrons can be determined from the ratio of two continuum emission intensities. The ion and atom temperature can be estimated from the ion-line emission profile through its doppler half-width measurement made with a conventional spectrograph. A rapid-scanning Fabry-Perot interferometer, which utilizes a piezoelectric oscillator and allows scanning of a line profile in 10^{-7} to 10^{-5} sec, has been obtained for the line-profile measurement. The operation of this interferometer requires an accurate synchronization of the interferometer scanning and the passage of the plasma (the shock wave) at the spectrograph slit. At the end of the year such a system of synchronization was under construction. The interferometer can also be used with a laser as a laser-interferometer for the independent electron-density measurement from the spectroscopic measurements described above. Since the optical emission only arises from the recombination behind the shock, it is desirable to obtain the electron-density measurement before the onset of the optical emission in order to compare the experimental results with the theoretical results described below. However, the range of electron densities attained in the present experiment favors a microwave-reflection technique rather than the laser-interferometry.

Nakagawa and Wu have examined the appropriate equations to describe the macroscopic relaxation phenomena under non-LTE conditions. These equations are to be used for the analysis of the experimental results described in the previous section. On the basis of a multifluid model, a set of macroscopic equations including radiation has been developed to the order of the Navier-Stokes equation. The results clarify the inconsistencies in the order of approximations in the macroscopic equations used previously by various authors, and the present results also indicate the effect of inelastic collisions. Utilizing these newly obtained equations, a model of shock structure for hydrogenic gas has been computed numerically; the preliminary results thus far obtained indicate several differences in the shock structures.

DISRUPTION OF WATER DROPS ON ELECTRIC FIELDS

Latham (LAS) and Roxburgh examined the stability of two water drops in an applied electric field, both experimentally and theoretically. Using the approximation that both drops were spheroidal and using the results of field enhancement for two spheres, a simple relation between the applied field strength and the distortion was calculated. This gave instability at a critical value of the electric field, and the theoretical and experimental results agreed to within a satisfactory error.

STARS

FORMATION OF CLOSE BINARY STARS

The early evolution of a rapidly rotating star was investigated by Roxburgh, and he found that conservation of angular momentum by each element of the star's radiative core could lead to a rotational instability capable of forming close binary systems. The agreement between theory and observation was highly satisfactory. This work was extended to consider possible evolutionary results of fission, and it was found that the observations of close binary systems with a sub-giant secondary inside its Roche limit were consistent with the hypothesis that such systems are in the postfissional stage of contraction towards the main sequence.

The internal structure of close and contact binary stars was examined by Roxburgh and Durney by extending techniques previously developed for rapidly rotating stars. Investigations were made first into the structure of polytropic binaries to determine whether it would be possible to have contact stars with mass ratios different from unity. It was found that unless there was a large-scale, dynamically driven circulation between the two stars one could not have a mass ratio different from one. The internal structure of such systems was determined. Investigations into the internal structure of close, highly distorted binary stars were undertaken to determine the effect of the distortion on the observational properties of such stars.

Roxburgh considered the evolution of close binaries with a view to determining the structure and stage of evolution of W. Ursae Majoris stars. Using the unpublished results of J. Faulkner on horizontal branch stars it was found that W. Ursae Majoris stars could be the evolutionary result of a close binary system that had undergone copious mass loss. The possibility of internal mixing in close binary stars was also investigated.

The effect of rotation on the stability and oscillation frequency of very massive stars, 10^8 to $10^{10} M_{\odot}$, was also considered by Roxburgh.

Using a simple virial theorem analysis, it was shown that rotation has a very important stabilizing effect and that the lifetimes of very massive, rapidly rotating stars were more than 10^4 years. Roxburgh, together with Durney, undertook a detailed stability analysis using the full general relativistic equations (in a weak field approximation), and this confirmed the virial theorem results.

STABILITY OF ROTATING WHITE DWARFS

The analysis used to determine the stability of massive stars was extended to white dwarfs to explore the possibility of general relativistic instabilities. Roxburgh found that instability occurred when the white dwarf parameter y_o = 37.2 for rapidly rotating stars as opposed to the value 22.6 for spherical stars. Together with Peter Strittmatter (a summer visitor at HAO), Roxburgh developed a code for determining monochromatic magnitudes for rotating stars and applied it to models of uniformly and nonuniformly rotating stars.

MAGNETIC STARS

In collaboration with S. Annand of the California Institute of Technology, Roxburgh evaluated the structure and stability polytropes with an internal magnetic field, and it was found that a magnetic instability, similar to the rotational instability, could arise during contraction toward the main sequence.

CLIMAX OBSERVING STATION

The Climax Observing Station continued operations with the instruments described in last year's report. Some increase occurred in the number of observing programs supervised by NCAR visiting staff and conducted by scientists from other institutions. In addition, most of the observing programs described last year are continuing.

Excellent prominence spectra near the Balmer limit were obtained with the 5-in. coronagraph for Hiei. Considerable testing and experimentation were required prior to the successful observations. The spectrograms show H_{20} 3684 A well resolved visually. We anticipate modifying the instrument in 1966 to facilitate greater UV transmission in an effort to obtain observations of the coronal Fe XIII line at 3388 A.

A study of solar spicules was initiated at the request of Robert Bessey of the University of Wyoming. The study calls for rapid, repetitive, spectrographic scans through the chromosphere to observe the evolution of an individual spicule.

The 16-in. coronagraph was used for several weeks during the fall by John Noxon of Harvard to measure coronal emission lines. Noxon fed light from the coronagraph to a recording spectrometer that was designed to measure day airglow. The technique involved the automatic subtraction of a sky spectrum from a spectrum containing both sky and emission lines. Successful measurements of 5303 A and 6374 A were obtained out to one-half radius from the limb. Line intensities considerably less than 10^{-6} of the solar disk were measured, and Noxon believes further improvements are possible.

MAGNETOGRAPH

The magnetograph was taken to Boulder and extensively modified during the year. Controls were installed to aid in observing as well as in data reduction. During calibration of the Zeeman data channel, the relay lens is now driven at 7.5 and 15 cps simultaneously. This has the advantage over voltage substitution in that any changes in the calibration signal may be compensated for in the data reduction. The magnetograph electronics were returned to Climax in mid-June; the system was checked out and restored to operation.

Rust moved to Climax in early July to gather magnetographic observations of prominences. He installed two field lenses near the double slit assembly that apparently solved a problem arising from the non-uniform cathode sensitivity of the phototubes. In addition, the response of the phototubes has been increased by placing prisms in front of the phototubes to allow the light to strike the cathodes at an angle of about 60° to the normal.

All of the efforts to improve the magnetograph were complete by October. At the end of the year 50 magnetograms of prominences had been obtained. Longitudinal field intensities in prominences were measured in the range from 2 to 20 gauss in this sequence of observations.

Analog-to-digital conversion of the magnetograph output is tentatively scheduled for completion by July 1966. This will facilitate rapid data reduction and allow for additional data to be recorded. The design, fabrication and implementation will be such that the anticipated down-time for the magnetograph will not exceed one week.

H-α SLIT MONITOR

The H-α slit monitor, an auxiliary instrument for the 16-in. coronagraph, was installed in August. The system was laid out optically by Rush and designed by Wendler. With this system both the slit and the image on the slit jaws are photographed on 35-mm film. The majority of our magnetic field measurements to data are complemented with these H-α filtergrams that show the configuration of the event and the slit position at the time the magnetogram was made.

SOLAR DATA REPORTING

The collecting and reporting of solar data and the management of the World Data Center A Solar Activity continued as in previous years.

The work of the International Quiet Sun Year produced some increase in the amount of data handled and in requests for data summaries.

HIGH ALTITUDE OBSERVATORY PERSONNEL, 1965

Director

John W. Firor

Scientific Staff

Martin D. Altschuler (from 21 July 1965)
R. Grant Athay
Sydney Chapman (combined appointment with the University of Alaska)
Bernard Durney (transfer from LAS, 1 April 1965)
John A. Eddy
Richard T. Hansen
Lewis L. House
John M. Malville (from 26 July 1965)
Sadami Matsushita
Friedrich Meyer (to 31 March 1965)
Yoshinari Nakagawa (transfer from LAS, 1 April 1965)
Gordon A. Newkirk, Jr.
Joseph H. Rush (on leave from 19 February to 20 December 1965)
Andrew Skumanich
Einar A. Tandberg-Hanssen
Dorothy E. Trotter

Visiting Scientists

Keith D. Cole (4 January to 15 September 1965)
Anthony Hearn (joint appointment with JILA)
Eijiro Hiei (to 31 August 1965)
Peter C. Kendall (30 August to 3 September 1965)
Julius London (21 June to 11 September 1965)
Hiroshi Maeda (to 6 August 1965)
Steven Musman (to 8 October 1965)
C. Abhirama Reddy (from 14 October 1965)
Ian W. Roxburgh (16 January to 24 September 1965)
Michael Rudge (19 July to 3 December 1965)
Takao Saito (from 3 June 1965)
Hermann Schmidt (to 9 April 1965)
Yutaka Uchida (to 28 June 1965)
James W. Warwick (4 June to 5 September 1965)

Climax Staff

Heinz Eichenseer
Charles D. Evans (from 14 June 1965)
Mary Lou James
Robert B. James, Station Manager
Werner H. Lindscheidt
John S. Lyons (28 June to 10 September 1965)
Chester B. Porter
Stephen R. Rogers
Angelina Sanchez
Juan F. Sanchez
Robert D. Shelley (from 22 October 1965)

Research Assistants

Ernest H. Amoral (to 8 June 1965)
David N. Anderson (transfer from LAS, 1 April to 6 August 1965)
Leslie B. Bruce (to 30 September 1965)
Karen S. Canfield
Peter Collins (to 29 June 1965)
Astrik Deirmendjian
Raymond A. Durand, Jr. (to 29 January 1965)
Arthur A. Few (to 31 August 1965)
Patricia A. Fisher (to July 1965)
Patrick R. Fuery (to 18 June 1965)
Charles J. Garcia (from 27 September 1965)
John E. Goff
Dianne S. Hackett (27 February to 8 April 1965)
Shirley Hansen (from 1 December 1965)
William A. Hatt (14 June to 17 September 1965)
Christiaan E. Heynekamp (to 30 September 1965)
Mary M. Hilty (from 18 October 1965)
George O. Hummer (to 30 September 1965)
Harrison P. Jones (7 June to 10 September 1965)
W. Dale King
John W. Kirkpatrick (deceased 16 October 1965)
Kathryn P. LaVelle
Ralph D. Lee (to 30 September 1965)
Carl G. Lilliequist
Fred L. Lohndorf (transfer from LAS, 1 April 1965)
Kathryn McKean
Wallace G. Minor (to 30 September 1965)
James L. Mudge (19 August to 30 September 1965)
Peter Okada (from 11 September 1965)
Charles W. Phillip (to 24 June 1965)
Jerry Roach (18 January to 19 February 1965)
Jean Ringstad (to 25 February 1965)
Charles L. Ross
William B. Sanborn (from 27 September 1965)

Virenda Saxena (from 29 November 1965)
Florence M. Scohy (from 1 June 1965)
Jean Snook (from 25 February 1965)
Peter R. Stevenson (to 30 June 1965)
William E. Stewart, Jr. (8 September to 30 September 1965)
Dallas E. Tanton
John E. Tam (from 8 October 1965)
Kenneth E. Terada (30 August to 29 December 1965)
Mary C. Travis
Francois Ulam (from 17 November 1965)
William J. Wagner (9 June to 20 September 1965)
Charles P. Wolfe
John W. Wood (to 6 September 1965)

Graduate Assistants

Richard C. Altrock
Lorne W. Avery (to 4 January 1965)
Richard L. Blake
J. David Bohlin
Richard C. Canfield
Robert P. Davies-Jones
William A. Deutschman
Richard D. Dietz (to 22 October 1965)
Richard R. Fisher (to 30 September 1965)
Mark A. Gordon
John W. Harvey
William Henze, Jr.
William R. Kuhn (to 14 June 1965)
Aharon Lavie
David M. Rust
Steven A. Schoolman (to 9 March 1965)(from 28 September 1965)
Billy A. Switzer (deceased 1 May 1965)
J. Daniel Tarpley, Jr.
Randolph J. Wolf (from 28 September 1965)
Shi-Tsan Wu (transfer from LAS, 1 April 1965)

Engineering and Instrumentation

Harold T. Braidwood
Stephen H. Broomell (to 2 April 1965)
Lendell W. Davidson (to 30 June 1965)
David E. Green
Robert G. Hanson
Howard K. Hull
H. David Hultquist
Philip S. Kuhn
Leon B. Lacey, Engineer-in-Charge, Machine Shop

Loren D. Laramore
Robert H. Lee, Engineer-in-Charge, Electronics Shop
Frank L. Melchior, Jr. (from 29 March 1965)
Bryan B. Southward
Robert F. Wendler
Werner J. Windbergs
Clyde M. Wyman

Administration and Office Staff

Clara G. Callahan
Cynthia H. Croft
Doris G. Fisher
Ruby L. Fulk
Darlene A. Hulett
Florence C. Lister (Librarian)
Constance S. Simpson (from 8 November 1965)
D. Keith Watson, Assistant to the Director
Dorothy L. Whitson (transfer from LAS, 1 April to 27 July 1965)
Eileen R. Workman

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Report of the

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.

Recognizing this opportunity to approach complex problems, and feeling a sense of responsibility to use it to best advantage, the Steering Committee and the Director of LAS have tried during the past year to see what directions should be followed, and what important tasks were being overlooked. In so organizing our thoughts we arrived at a sort of blueprint for a long-range atmospheric science research plan, one that might apply to the scientific community as a whole as well as to NCAR. We mention this blueprint here, since it will help to put the activities of the LAS into a proper perspective, and the reader can decide for himself how well we seem to be steering for our destinations.

The ultimate goal of scientists, as of public spirited people everywhere, is the betterment of the lot of mankind. In the atmospheric sciences there are three main challenges, the achievement of which would lead to the benefit of everyone, and these may be thought of as our human goals. They are:

A. Improved predictions of the weather

B. Weather and climate modification

C. Conservation of the atmosphere

One can think of other goals, but these three must surely remain the most important and all-inclusive.

To achieve these goals certain classes of scientific and engineering problems must be solved, and we have, again, identified three broad problem areas. They are:

a. The general circulation

b. Physics of clouds and precipitation

c. The life cycles of trace gases and aerosols

Indeed, these broad problem areas are not independent, since solutions in one area will contribute to the others, but together they encompass nearly all the important phases of atmospheric science -- though not quite all.

How they relate to the human goals is fairly obvious; each of the goals will be approached by advances in any of the problem areas, but there is a stronger correspondence between a. and A., between b. and B. (at present), and certainly between c. and C.

Next, we wondered: what are the chief ingredients of each of these broad scientific and engineering problem areas? These would be the individual hurdles that we would have to pass over in order to solve a broad problem. The list that we drew up was long, and most instructive. It will not be reproduced here in toto, but interestingly enough it reads very much like the table of contents of this LAS report. In fact, it was most gratifying to see that, with a few exceptions, we are already addressing ourselves to the main hurdles.

Next year we hope to address ourselves, in a preliminary way, to some of the hurdles that we have identified but are not yet attacking adequately. Those specific scientific problems that we are determined to emphasize (even at the expense of some other parts of the program if necessary) are the role of cumulus convection in the tropics and the measurement of meso-scale motions (motions on the scale of 0.1 to 100 km).

Two other major problem areas requiring a combination of engineering development and scientific planning and guidance are the global weather observing system and the special purpose super-computer, both needed for the general circulation problem, and both developments to which we expect to be deeply committed for many years. In fact, it appears that our theoretical knowledge of the general circulation has already outstripped our ability to observe the atmosphere on a global scale (with less than 20% of the Earth's area adequately equipped with weather observing stations); and at this point we could design much better theoretical models of the atmosphere if we had faster computers with bigger memories (or capable of parallel-mode operation). Both of these developments, but particularly the global weather observing system, will involve several governmental agencies, rather vast amounts of financial support, and the cooperation of scientists in other countries; but it is clear that an essential ingredient for the success of these ambitious ventures will be the support of the university community of the United States, in which NCAR must continue to play a most active and central role.

Returning to LAS and its mode of operation, it would be an empty exercise indeed if the efforts of its Director and the Steering Committee to identify the key scientific problem areas were not discussed at length with the scientists of LAS -- in fact, if they did not themselves help in setting the course of LAS. A sense of identification of the individual with the aims of the group can only come, it seems to us, if there is free and amiable communication on all sides. It is not enough to remove barriers; the channels of communication must be constantly cleared and overhauled.

To achieve this internal communication there are frequent seminars during the year, some of them well structured and continuing, some informal and one-shot affairs. The visitors to NCAR, of course, as well as the staff, contribute a great deal to these. Then, in September 1965, the LAS again had a three-day meeting away from Boulder (near Estes Park), where in a leisurely atmosphere there could be an uninterrupted time for discussion of our scientific program, past and future. The theme this time was "the general circulation" (broad scientific problem area A above), and the discussion was organized by Associate Director of NCAR Philip D. Thompson (original Director of LAS). It was significant that virtually every scientist in LAS had something to contribute from his own work to this fundamental and important subject.

It is also significant that as a result of this meeting a number of new collaborations between programs were begun, and will probably begin to bear fruit next year.

As a final remark, we must add that the attempt we have made to guide and structure our program of atmospheric research is not without its dangers. Research, since it is by nature a venture into the unknown, cannot be expected to have a very predictable product. History is full of the stories of unexpected discoveries, where a restless inquiring mind gained a special insight into some mystery of nature -- without a plan or "research program" guiding his way. So, we must be careful not to guide the research of LAS <u>too</u> strongly, but to protect the freedom of choice for the individual scientist. We are striving to provide an environment at NCAR that will stimulate him to work in those areas where he can contribute the most to the field of atmospheric science -- this, we believe, is the best sort of guidance.

William W. Kellogg
Director

MOTIONS IN THE ATMOSPHERE

LARGE-SCALE MOTIONS IN THE ATMOSPHERE

The atmosphere can be described as a restless fluid in continuous motion, driven by the heat of the sun and the cold of space. In fact, its most obvious feature is this motion, and "the weather" is to a large extent characterized by the wind -- and by what is carried or produced by the wind. So it is not surprising that atmospheric motions on all scales occupy the center of the stage in the arena of meteorology, and understanding and predicting them presents a major challenge to meteorologists.

The largest scale of motion is referred to as "the general circulation," in which the winds and temperature fields at all levels over most of a hemisphere are conceived as a single complex and interacting pattern. To understand the real atmosphere, artificial atmospheres or "models" can be constructed mathematically and made to perform on a computer -- the success of a model being to some degree measured by how much its motions and temperature distributions resemble the real atmosphere.

This kind of test of a mathematical model naturally suggests that a companion effort must be made to improve our description of the real atmosphere. Since meteorological observations are never adequate to define the state of the atmosphere completely, the synoptic meteorologist must patiently piece together and interpret such evidence as he has, in this way reconstructing as realistic a picture as possible and at the same time gaining insight into the many complex interactions that take place in nature. He must carry on this descriptive work at all scales of motion, from the hemispheric patterns where he works with global weather observations, to the rapid fluctuations in the boundary layer, where he may work with closely spaced and rapidly responding instruments. But first we will deal with the larger scales.

General Circulation Numerical Experiments

As reported in the NCAR Annual Report, 1964 (pp. 153-154), Akira Kasahara and Warren Washington are working on the design of a general circulation model of the atmosphere. The purpose of this undertaking is to simulate the large-scale motions of the atmosphere by the numerical integration of relevant thermo-hydrodynamic equations on high-speed computers. It is hoped, eventually, that the model can serve as a numerical "laboratory" of the atmosphere with which to test a wide variety of hypotheses and to make new discoveries. A feature of the Kasahara-Washington model is the use of height as the vertical coordinate, though the hydrostatic law replaces the vertical component of the equation of motion. The formulation of the model closely resembles the prediction scheme proposed by L. F. Richardson in the 1920s, which has not yet been extensively tested. It is felt that a further exploration of the Richardson scheme is a worthwhile effort. This model includes such atmospheric ingredients as energy transfer processes due to short- and long-wave radiation, turbulent and convective motions in the planetary layer, effect of the release of latent heat, etc.

The first complete NCAR model (Model I) uses a grid network consisting of five height-levels plus the surface level with a vertical spacing of 3 km, and covers the entire globe with a horizontal spacing of 5° in both longitude and latitude. This machine program takes 4 hr to run on the CDC 3600 for a one-day "forecast" with time steps of 5 min, or a ratio of machine time to real time of 1:6. It soon became evident that such a speed of computation was too slow to debug the machine code efficiently. Therefore, to facilitate the check-out of the model, it was decided to code a faster program (Model II) by reducing the vertical resolution to only two levels with a vertical spacing of 6 km, and by reducing the horizontal resolution to a grid spacing of 10° in both longitude and latitude. This simpler machine program runs on the CDC 3600 with a time ratio of 1:100. The program check-out is greatly aided by a piece of auxiliary computer equipment, the dd80, recently installed at the NCAR Computing Facility. This is a visual data display unit attached directly to the CDC 3600 computer, by which contour maps can be plotted on a cathode ray tube, while an attached cine camera takes pictures of the model map on 35-mm microfilm.

Another machine program has been completed by Kasahara and Washington, in collaboration with Takashi Sasamori (visitor from Japan) and Julius London (University of Colorado), to evaluate infrared radiative fluxes and heating by water vapor, carbon-dioxide and ozone in the atmosphere, factors eventually to be incorporated into the general circulation model. The program utilizes the radiation tables compiled in 1960 by W. M. Elsasser and M. F. Culbertson, and the transfer equations are solved by a numerical quadrature.

A simpler version of a general circulation experiment, designed by Philip Thompson and described in the 1964 Annual Report, is also being developed with the assistance of Washington.

The Influence of Orography on Large-Scale Flow

In an attempt to understand the dynamical influences of the Earth's orography upon the large-scale motions of the atmosphere, Kasahara performed a series of numerical integrations based upon the equations governing the motion of a barotropic fluid with a free surface. Flows around and over a circular mountain with a 1500 km radius and a 2 km height were investigated in detail. The main results are the following: (1) Westerly flows past the mountain produced a train of long waves on the lee side, which can be identified as "planetary" waves; on the other hand, easterly flows are little disturbed by the obstacle and long waves do not appear. (2) The number of waves produced in the westerly wind cases agrees with the number expected from the steady-state Rossby-Haurwitz wave formula for various intensities of zonal flow past the obstacle. These theoretical results compare favorably with the experimental data obtained in the early 1950s by D. Fultz, R. Long and P. Frenzen, who performed laboratory experiments on the flow past an obstacle in a rotating hemispherical shell. A theory was proposed to explain the characteristic differences between westerly and easterly flows past the obstacle that were observed in the numerical experiments [1].

Atmospheric Energy Diagnostics

To obtain further insight into the complex way in which atmospheric kinetic energy is partitioned between the zonal flow and the large-scale eddies, and also between the various scales of the eddy motions, investigations have been carried out by John Brown using analyzed northern hemispheric data. The diagnostic energy calculations of the conversion of available potential energy into kinetic energy were made with the intent of studying the effects of various techniques and assumptions on the calculated energy values. For this purpose it is important to evaluate large-scale motion patterns accurately. Numerous tests indicated that the magnitudes of such energy conversions differ significantly from each other depending on the methods by which the large-scale vertical motion patterns are calculated. The use of the omega equation in calculating the vertical motions seems to be satisfactory when compared with the adiabatic method or the vorticity equation technique, but further improvements in the omega equation technique seem to be desirable, particularly in connection with the lower boundary conditions. Further attempts to adopt more realistic lower boundary conditions are being pursued.

In addition to the above investigations, comparative studies are being made on the magnitudes of energy conversions by using three different sets of upper air maps for the period of January 1964, objectively analyzed by the National Meteorological Center, U. S. Weather Bureau, and the U. S. Air Force and the U. S. Navy. Although the monthly mean values do not differ appreciably in these sets, much larger differences are found on individual days, particularly in the case of the zonal conversions. The major region contributing to these differences was

1. Kasahara, A.: "The Dynamical Influence of Orography on the Large-Scale Motion of the Atmosphere," NCAR Ms. No. 64, presented at the International Symposium on Dynamics of Large-Scale Processes in the Atmosphere, June 1965, Moscow, USSR; accepted for publication by the Journal of the Atmospheric Sciences.

that south of 35°N latitude in the Northern Hemisphere, where upper air observations are generally very scarce.

Short-Range Forecasting Model

Bengt Söderberg (a visitor from Sweden) together with Ragnar Fjørtoft (from Norway, recipient of the Rossby Fellowship of the American Meteorological Society, and a staff member in the Advanced Study Program until July 1965) made a number of numerical experiments with a multilevel hemispheric prediction model. This study originated in the desire to formulate a short-range forecasting model with high vertical resolution in connection with the study of so-called "empirical orthogonal functions" of atmospheric variables, and to investigate their possible application to optimizing the presentation of parameters used in numerical weather prediction. The model assumes a balance between the wind and geopotential fields, as proposed by R. Fjørtoft in 1962. In the experiments, the vertical distributions of meteorological variables are given at 11 pressure-levels between 50 and 950 mb. The grid distance is 381 km at 60°N on a stereographic projection. In the first phase the model has been programmed for a grid covering 17 x 17 x 11 points. A program covering 31 x 31 x 11 grid points is in the final stages of debugging. A considerable improvement was made over the scheme suggested originally by Fjørtoft to speed up the convergence in the balancing procedure. Although Fjørtoft's scheme can handle, in principle, computations in the region of hyperbolicity, it was found desirable to eliminate such a region, since a formal balancing in the hyperbolic region is not appropriate from a physical point of view. A number of successful 36 to 48 hr forecasts were made. The results of the present forecasts were definitely superior to the published results obtained by other forecasting methods applied to the same meteorological situation, including a two-layer primitive equation model. The dd80 optical display unit attached to the CDC 3600 computer is being used to make movies of the time-dependent forecasting patterns [2].

George Morikawa (a summer visitor from the Courant Institute of New York University) has worked on deriving approximate asymptotic equations which describe slowly varying planetary-scale motions of the atmosphere by using a systematic approximation procedure. A numerical study of these asymptotic equations seems to be necessary to test their validity for describing actual atmospheric motions.

Finite-Difference Integration Methods

Since the accuracy of finite-difference schemes largely determines the degree of success of numerical weather predictions, it is important to continue the search for the best finite-difference equations for geophysical fluid problems. A review of this subject has been made by Akira Kasahara [3]. Another paper by David Houghton, Akira Kasahara, and Warren Washington is concerned with various effects of altering the boundary formulation, varying the coefficient of viscosity, and changing the formulation for the Coriolis term upon the long-term (100 days) integrations of the barotropic equations [4].

David Williamson has investigated the stability of finite-difference schemes for partial differential equations of fluid dynamics containing alternatively both diffusion and advection terms, advection and inertia terms, or all three terms [5].

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2. Fjørtoft, R. and B. Söderberg: "A Prediction Experiment with Filtered Equations," NCAR Ms. No. 59, a preliminary report.

3. Kasahara, A.: "On Certain Finite-Difference Methods for Fluid Dynamics," Monthly Weather Review 93, 27-31, 1965.

4. Houghton, D., A. Kasahara and W. Washington: "Long-Term Integration of the Barotropic Equations by the Lax-Wendroff Method," NCAR Ms. No. 58, accepted for publication by the Monthly Weather Review.

5. Williamson, D.: "Stability of Difference Approximations to Certain Partial Differential Equations of Fluid Dynamics," NCAR Ms. No. 95, submitted for publication in the Journal of Computational Physics.

When atmospheric prediction equations are solved numerically, truncation errors ordinarily appear in the course of approximating both the time and space derivatives by finite-difference schemes. Effects of time truncation errors have not been investigated as much as those of space truncation errors. Ferdinand Baer (a visitor from Colorado State University) has been working on the evaluation of time truncation errors in solving the barotropic vorticity equation by comparing the numerical solutions, obtained by various time differencing schemes, against the known exact solutions.

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The sections above have dealt mostly (though not exclusively) with theoretical studies in which mathematical techniques and computers were used to simulate the atmosphere. This is the area of the numerical model builders, or the dynamic meteorologists. Now we turn to the domain of the synoptic meteorologists (though we should emphasize that there is no wall between these domains), and the next few sections describe research aimed at clarifying the way the atmosphere behaves, using observations. Unfortunately, weather observations are still scarce in the upper atmosphere and in many vast regions of the world, including most of the oceans and most of the Southern Hemisphere. Thus, there is a need for careful analysis and thoughtful deductions in order to piece together a reasonable picture from the fragments.

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Index Cycle

One of the traditional concepts of extended-range forecasting is the "index cycle," described qualitatively as a series of circulation patterns characterized by alternating periods of great and small strength of the westerlies, accompanied by latitudinal shifts of the position of the band of strongest winds. Such a sequence has been supposed to occur with a preferred periodicity suggesting that, once the pattern has begun, the timing of the remainder of the cycle can be forecast. Utilizing 21 years of 700-mb zonal index data, Paul Julian made a quantitative examination of the evidence for or against the existence of an index cycle. An exhaustive cross-spectrum analysis did not indicate that the sequence of patterns occurred with particular range of period.

Southern Hemisphere Meteorology

As discussed in last year's report, the middle-latitude westerlies of the Southern Hemisphere are stronger in summer than in winter [6]. This is connected with the fact that the meridional temperature gradient at the Earth's surface is stronger in summer, the influence of this being felt in greater vertical (thermal) wind shear through a deep layer of the troposphere in that season. This behavior reflects the circumstance that the highest annual temperature range occurs near 35°S, and the lowest near 50°S. The reason for this has been examined by Harry van Loon. An energy budget for the surface layers of the ocean indicated that the smaller annual range in higher middle latitudes can be attributed to the combined effect of mitigation of radiation influences by clouds, and of the mixing of heat to greater ocean depths at 50°S, presumably owing to more vigorous stirring by strong winds at that latitude [7].

Van Loon is also currently searching for the cause of certain seasonal anomalies in the Southern Hemisphere circulation. A reversal of the normally expected temperature trend in May-June over the Ross Sea--South Pole region is apparently linked with a shift of the long

6. van Loon, H: "A Climatological Study of the Atmospheric Circulation in the Southern Hemisphere during the IGY. Part I," Journal of Applied Meteorology 4, 479-491, August 1965.

7. van Loon, H: "The Annual Range of Surface Temperatures in the Southern Hemisphere and its Implications for the Atmospheric Circulation," NCAR Ms. No. 54, accepted for publication by the Geographical Review.

waves, presumably initiated by the cooling of Australia. The pressure variations over Australia have a pronounced annual component, with winter maximum and summer minimum, clearly connected with seasonal heating and cooling. Over the neighboring oceans at 35 to 55°S the pressure variation shows a stronger semiannual component, with maxima near the equinoxes and minima near the solstices (demonstrated by W. Schwerdtfeger and F. Prohaska in 1956). As a result, the east-west pressure gradients over the ocean areas both to the east and west of Australia (particularly to the east) reach maximum strength in June. On the Antarctic coast there is also a dominant semiannual pressure variation which is, however, opposite in phase to that over the middle-latitude oceans. Connected with this, there is a semiannual rather than annual variation in the pressure (and temperature) gradients between 50°S and Antarctica. The causes of these pecularities appear to lie in differences in the rates and amplitides of seasonal cooling and heating in the various regions.

As a longer-range effort, van Loon will collaborate with Julius London (of Colorado University) and J. J. Taljaard (a visitor from South Africa) on studies of the Southern Hemisphere heat balance and circulation. With Aylmer H. Thompson (Texas A and M University), he will analyze long-wave radiation and cloud data from Tiros VII covering an 11-day period in December 1963. As a further contribution to these Southern Hemisphere studies, Henry van de Boogaard has carried out computations of the fields of geopotential, momentum and kinetic energy in relation to wave number, using 500-mb grid-point data for that hemisphere, furnished by the South African Weather Bureau for the first nine months of the IGY.

Tropical Circulations

Based on an earlier analysis,* Henry van de Boogaard has studied the distribution, transport and conversion of kinetic energy in the equatorial and subtropical latitudes of the Northern Hemisphere. Although only a single day's data are involved, the use of all available actual winds at seven levels in this circumhemispherical analysis makes it possible to evaluate important features not revealed by less detailed analyses over a longer period.

Distributions in the meridional plane of the kinetic energies of the zonally averaged west-east and south-north flow and of the zonally averaged perturbations of the two components were determined separately. A comparison shows that in the upper troposphere the energy of the mean meridional flow can be entirely neglected in subtropical latitudes; near 12°N, where this flow is most intense, it becomes of a corrective nature. At low levels at this latitude the value is comparable with that of the other three fields. Surprisingly, the kinetic energy contained in the eddies was comparable for the zonal and meridional flow components, and also comparable to the kinetic energy of the zonal mean flow. Transports of kinetic energy across latitude circles, by the mean meridional circulation and by eddy motions, were found to be about equal in tropical latitudes, while in subtropical and higher latitudes the eddy transport dominated.

Computations of energy conversion by the mean and eddy motions showed that the energy conversion by eddies is small compared with the release due to the mean circulation in the Hadley cell. Utilizing the energy budget equations developed to their fullest extent, the non-geostrophic terms were evaluated and found to be comparable to the geostrophic terms, showing that their omission may lead to invalid conclusions as to the dynamics of the tropical and subtropical atmosphere.

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* Defant, F. and H. M. E. van de Boogaard: "The Global Circulation Features of the Troposphere between the Equator and 40°N, Based on a Single Day's Data. Part 1. The Structure of the Basic Meteorological Fields," Tellus 15, 251-260, August 1963.

In investigating the above processes on a time-dependent basis, analyses will be carried out over the continent of Africa where tropical data are most abundant. Analyses have been started which include six days of each mid-season month, and computations similar to the above (and including water-vapor and heat budgets) will be performed. Particular attention will be paid to hemispheric interactions over this region.

Stratospheric Circulation

Having completed a study (with Karen Labitzke, visitor from Free University of Berlin) of the relationships between stratosphere and troposphere during a stratospheric warming event [8, 9], Paul Julian is further investigating the behavior of planetary waves before and during the warming phenomenon. This is in continuation of investigations discussed in the 1964 Annual Report [10]. To obtain better vertical motion estimates for calculation of energy conversions, a diabatic cooling term has been incorporated into the omega equation. Karen Labitzke and Harry van Loon have also published a note on stratospheric warmings in the Southern Hemisphere, in which evidence is given suggesting a linkage between warming events and circulation changes in the troposphere [11].

Utilizing aerological observations by the Finnish-Swedish-Swiss IGY Expedition, L. A. Vuorela (summer visitor from the University of Helsinki) made time-section analyses over Spitzbergen embracing the

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8. Labitzke, K.: "On the Mutual Relation between Stratosphere and Troposphere during Periods of Stratospheric Warmings in Winter," Journal of Applied Meteorology 4, 91-99, February 1965.

9. Julian, P. R. and K. Labitzke: "A Study of Atmospheric Energetics during the January-February 1963 Stratospheric Warming," Journal of the Atmospheric Sciences 22, 597-610, November 1965.

10. Julian, P. R.: "Some Aspects of Tropospheric Circulation during Midwinter Stratospheric Warming Events," Journal of Geophysical Research 70, 757-767, February 1965.

11. Labitzke, K. and H. van Loon: "A Note on Stratospheric Midwinter Warmings in the Southern Hemisphere," Journal of Applied Meteorology 4, 292-295, April 1965.

stratospheric warmings in midwinter 1957-58. In contrast to the bimodal frequency distribution of temperatures at around 100 mb found over eastern North America and Greenland, the Spitzbergen data suggest a unimodal distribution with relatively low temperatures predominating. In the stratospheric warming of late January 1958, there appeared to be a coupling between a developing tropospheric vortex and the stratospheric circulation. During the second and most intense warming of February 10 that year, however, there was no phase correlation between stratospheric and tropospheric waves. Stratospheric vertical motions were generally small, except during the stratospheric warming period. It was concluded that the temperature rise was largely due to horizontal heat advection, so far as this particular locality was concerned.

Ocean Currents

Several years ago C. G. Rossby emphasized that the dynamical processes in atmospheric and oceanic current systems should be essentially similar, and that these systems may profitably be studied in concert. Many geometrical similarities have been found between the Gulf Stream and the jet stream. To these, Chester Newton has added the observation that parcels of water in the Gulf Stream undergo the same kind of semi-inertial oscillations as were described for the jet stream in last year's report. Streaks of high-velocity current alternate with weaker velocities along the Stream; on the average about a full pendulum day appears to be required for water parcels in the core of the current to pass through one of these streaks [12].

Climatic Change

In an attempt to obtain quantitative evidence of climatic changes prior to the era of weather records, Paul Julian has entered into a project for the analysis of tree-ring and climatic data. There is

12. Newton, C. W.: "Semi-Inertial Velocity Variations along the Gulf Stream," NCAR Ms. No. 10, accepted for publication by <u>Deep-Sea Research</u>.

already good evidence that a statistical analysis of ring widths taken from tree cores can give some information on the amount of precipitation for the winter and spring seasons preceding the growing seasons of trees. A program of coring trees along the foothills and hogbacks from Fort Collins to Denver was completed during the summer, by the Laboratory of Tree-Ring Research of The University of Arizona, which is cooperating in the investigation. Six excellent, homogeneous meteorological observing stations are located along the foothills in this part of Colorado, and in a few instances trees within a mile of the stations were sampled. One of the uncertainties in establishing tree-ring and climate relationships, that of the distance between the basic observations, was thereby minimized. Analysis of the ring data by the University of Arizona and of the meteorological data by NCAR has begun.

Monograph on Synoptic Aerology

In collaboration with Professor E. Palmén of the Academy of Finland, Chester Newton continued preparation of a monograph on Synoptic Aerology, writing chapters on the jet stream and on convective systems. This is expected to be finished in spring, 1966. The subject matter embraces mainly the general circulation and the structures of atmospheric disturbances of cyclone scale, both extratropical and tropical, with their physical interpretations.

MEDIUM- TO SMALL-SCALE MOTIONS IN THE ATMOSPHERE

An evident limitation to the large-scale models is the fact that no modern computer has enough capacity to deal with the whole atmosphere using a grid much finer than 500 km on a side. Anything finer would simply require too much computation. To see what happens at the medium scales of motion it is necessary to develop special and somewhat different models, each designed to simulate a particular set of conditions. Thus, for example, one model will show the dynamics of a hurricane, another a mountain wave, another a jet stream, another a cumulus cloud, and so on. In principle, with much larger computers, these features could be studied in the context of a general circulation model in which all scales of motion are represented (as they should be), but for the time being we must be content with making special piecemeal models. And indeed, from these special models we can learn a great deal.

We will reserve for a following section the discussion of the class of motions generally considered as "turbulent." Actually, there is no clear distinction between convective motions, taken in the aggregate, and turbulence -- it is a matter of scale or perspective to some extent, and the distinction is not important. We have separated them here merely for convenience.

Jet Streams

David Houghton has continued to work on a dynamical study of jet streams. He made a spectral analysis of jet flow in a barotropic fluid with a free surface. The lines consisting of the same particles are used as the coordinate system to delineate north-south variations, and the standard Eulerian representation for the east-west direction. The results indicate the feasibility of such an approach for the prediction of barotropic jet streams up to about 72 hours [13]. At present Houghton is investigating the question of intensification of horizontal gradients of vorticity in a jet stream in the barotropic atmosphere.

An investigation of the structure of the subtropical jet stream and the accompanying high-tropospheric fronts, mentioned in the 1963 Annual Report, was published by Chester Newton [14]. Another study, by Newton and Yukio Omoto (a visitor from Japan), outlined in the 1964 Annual Report, indicates that in middle-latitude waves the high-tropospheric jet stream is (considering short periods of time) advected

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13. Houghton, D.: "A Quasi-Lagrangian Study of the Barotropic Jet Stream," Journal of the Atmospheric Sciences 22, 518-528, 1965.

14. Newton, C. W.: "Variations in Structure of Subtropical Current System Accompanying a Deep Polar Outbreak," Monthly Weather Review 93, 101-110, February 1965.

with the wind, air particles in the jet-stream core conserving their total energy [15].

Flow over a Mountain

Boulder and other areas along the eastern slope of the Rockies are struck from time to time, during winter and spring, by strong winds which suddenly flow down from the mountains. To understand the nature of flows over the mountains, Akira Kasahara performed numerical integrations of the one-dimensional time-dependent "shallow water" equations. It was learned that the flow over a mountain can produce a sudden hydraulic shock on the lee side of the mountain when the velocity of flow on the windward side exceeds a critical value. At the shock the flow is extremely strong and gusty. Similar phenomena are often found in river flows over rocks. The many similarities between the characteristics of the computed flows over the mountain and "observed" ones in the Boulder area, have encouraged Kasahara to conduct further research in collaboration with David Houghton and Eugene Isaacson (Courant Institute, NYU). The dd80 data display unit is being used extensively to make movies demonstrating the time-dependent solutions of the flow over the mountain. The results of the one-dimensional calculations compare favorably with the laboratory data obtained by Robert Long (The Johns Hopkins University). Houghton is extending the work of the present one-layer model to the two-layer model, incorporating the effects of wind shear and thermal stratification. The machine program of the two-layer mountain flow model has just been completed.

Douglas Lilly is pursuing a related observational study of mountain waves and associated surface winds in the Boulder area. The Field Observing Support Facility has provided seven recording anemometers which, together with several others already in operation, are being located in a network extending from the Continental Divide to about 50 miles to the

15. Newton, C. W. and Y. Omoto: "Energy Distribution near Jet Stream and Associated Wave-Amplitude Relations," Tellus 17, 449-462, November 1965.

east . The three-dimensional velocity and thermal structure will be investigated by means of constant-volume balloons and airplane flights.

Cumulus Convections, Cloud Populations, and Interactions with Large-Scale Motions

Almost half of the Earth's atmosphere lies over the tropical oceans, and in this region, plus much of the middle latitudes during summer, convective clouds are a dominant climatological feature. The work of J. Malkus (Simpson) and others has shown the importance of these cloud populations in the general circulation, and recent observations by Garstang and Simpson suggest that they interact strongly with the large-scale dynamics in characteristic tropical disturbances. At NCAR Douglas Lilly is attempting to develop a theoretical framework for quantitatively incorporating cloud population statistics into the large-scale dynamic equations and using these modified equations to deduce stability criteria for disturbance development. To formulate the theory one must be able to predict cloud population characteristics from a given set of large-scale parameters, and for this purpose a large program of numerical simulation of cloud convection is under consideration. Systematic analysis of aircraft, satellite and conventional meteorological data will be necessary. The crude assumptions made so far lead to several potential instability mechanisms associated with cloud convection, some of which seem to show considerable similarity to observed tropical disturbance features.

While the total effects of cloud populations, being studied by Lilly, need to be considered for general circulation models, it is equally important for many other purposes (e.g., cloud physics, aircraft operations, hail studies, etc.) to understand the details of the development of a single cumulus. The development of new observational tools for studying convection is treated in the section on Condensation and Freezing Nuclei (p.100). Here we discuss some of the more theoretical approaches.

During a short visit from St. Louis University, Fred C. Bates, in cooperation with Chester Newton, laid out a program for computing the kinematical properties and the forms of updrafts and downdrafts in cumulonimbus clouds subjected to the influence of shear. Preliminary results indicate that under typical conditions of instability and vertical wind shear the horizontal velocities inside drafts differ by as much as 25 m/sec from the environmental wind. In a travelling storm the updraft tilts in an upshear direction (that is, in a direction opposite to the wind-shear vector between cloud base and top), typically at an angle of about 45° from the vertical. Air entering the base of the updraft, on the advancing side of the storm, traverses through it and appears on the upshear side as a tower penetrating into the stratosphere. A thermodynamic analysis by Newton indicates that the updraft air, part of which penetrates the tropopause and returns to the troposphere in downdrafts, remains in the upper troposphere where it feeds the expanding anvil plume at a rate of the order 2 km^3/sec of cloudy air in a single large thunderstorm. A separate downdraft in lower levels originates in the middle troposphere, and plays an essential role in forcing the continuous regeneration of updrafts [16].

It is planned to continue this work by more extensive computations embodying varying thermodynamic processes. The results are expected to have some significance for studies of the general circulation, contributing to an assessment of the vertical exchange of horizontal momentum, heat, and moisture in convective clouds. There are also implications in the area of cloud physics, since the growth of precipitation particles is partly dependent on the motions of the air carrying them.

In a popular-style article, Chester Newton and James C. Fankhauser (visitor from the Weather Bureau) described findings related to the movements of thunderstorms [17]. The study was also outlined in the 1964

16. Bates, F. C. and C. W. Newton: "The Forms of Updrafts and Downdrafts in Cumulonimbus in a Sheared Environment," NCAR Ms. No. 108, presented at the AMS Conference on Cloud Physics and Severe Local Storms, October 1965, Reno, Nevada.

17. Fankhauser, J. C. and C. W. Newton: "The Migration of Thunderstorms as Related to Wind and to Moisture Supply," Weatherwise 18, 68-73, April 1965.

Annual Report. This and other aspects of storm behavior are discussed by Newton in a general review article [18].

Previous studies on the column model of a cumulus convection conducted by many investigators were concerned primarily with the physical forms of buoyant elements in the updraft and the mechanism of entrainment of the environmental air into the updraft. In all of these studies of the structure of cumulus clouds, the models consist of only a single column of updraft in a surrounding still atmosphere, and no consideration is given to the effects of the compensating downward motions associated with the updraft. From observations of cumulonimbus clouds and of Bénard cell convections, it is evident that the role of downward motions is very important when considering the updraft.

Tomio Asai (a visitor from the Meteorological Research Institute of the Japan Meteorological Agency) and Akira Kasahara are undertaking a numerical study to assess the effects of the compensating downward motions upon the development of a cumulus convection. The model consists of two circular concentric air columns: the inside column (core) is for the updraft region (cloud area) and the outside concentric band is for the downdraft region (clear air area). A preliminary result indicates that the downward motion plays the role of "brake," preventing the growth of the updraft [19]. Asai has also continued his study of air-mass modification, as described in the NCAR Annual Report, 1964 (p.165) [20, 21].

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18. Newton, C. W.: "Severe Convective Storms," in Advances in Geophysics, Vol. 12, Academic Press, New York, in press.

19. Asai, T. and A. Kasahara: "The Influence of Downdraft on the Development of a Cumulus Convection," NCAR Ms. No. 109, presented at the Fourth Technical Conference on Hurricanes and Tropical Meteorology, November 1965, Miami, Florida.

20. Asai, T.: "A Numerical Study of the Air-Mass Transformation over the Japan Sea in Winter," Journal of the Meteorological Society of Japan, Series II, 43, 1-15, 1965.

21. Asai, T.: "Air-Mass Modification over the Ocean off the East Coast of Continents in Winter," presented at the annual meeting of the Canadian Branch of the Royal Meteorological Society, June 1965, Vancouver, B. C.

Thermal Convection and Boundary Layer Turbulence

Measurements have been completed by James Deardorff and Glenn Willis on the statistics of thermal turbulence generated in a laboratory convection chamber [22, 23, 24]. These results have been used to test a pseudo three-dimensional numerical model of turbulent convection. This model yielded essentially correct values of turbulent heat flux, but gave twice too much temperature variance and too little vertical velocity variance. It has been concluded that a fully three-dimensional numerical model is preferable, even though the spatial resolution feasible in three dimensions is much less than that in two dimensions. A fully three-dimensional model has therefore been developed; it differs from that developed by Warren Washington in several respects. The remaining problem to be solved is the satisfactory representation of the effects of eddies too small to be resolved by the numerical grid network. While theoretical work is in progress on this difficult subject, the three-dimensional model is being tested against laboratory Couette and Poiseuille flows, for which the effects of sub-grid scale motions are minimal. Temperature differences will be added to the model after the larger computer, the CDC 6600, is operational. The ultimate goal is to simulate numerically the turbulence which occurs near the Earth's surface and on scales too small to be resolved within a model of the atmosphere's general circulation, and to gain a detailed understanding of this turbulence. Although this goal is distant, the simulation of laboratory turbulence is an important first step.

A three-dimensional thermal convection problem is also being studied by Warren Washington. One feature of Washington's approach is

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22. Deardorff, J. W.: "Gravitational Instability between Horizontal Plates with Shear," Physics of Fluids 8, 1027-1030, June 1965.

23. Deardorff, J. W.: "A Numerical Study of Pseudo Three-Dimensional Parallel-Plate Convection," Journal of the Atmospheric Sciences 22, 419-435, July 1965.

24. Deardorff, J. W. and G. E. Willis: "The Effect of Two-Dimensionality on the Suppression of Thermal Turbulence," Journal of Fluid Mechanics 23, part 2, 337-353, 1965.

the solution of the set of relevant equations in the primitive rather than the vorticity form. This leads to a considerable saving in computing time, though the finite-difference formulation requires special care, particularly in connection with the boundary conditions. The two-dimensional version of his program has worked successfully [25]. The present CDC 3600 computer has insufficient core storage for a fully three-dimensional calculation, and therefore only low resolution experiments covering grid points 11 x 11 x 11 are performed. The preliminary results indicate that the model is capable of simulating three-dimensional convection cells, and they are being compared with those obtained by James Deardorff, who has also been working on the three-dimensional convection problem from a different approach. Higher resolution calculations are being planned for the new CDC 6600 computer.

BASIC-FLUID DYNAMICS, BOUNDARY LAYERS, AND THE PROBLEM OF TURBULENCE

The preceding sections have dealt, principally, with the great driving forces and principal energy-containing motions of the atmosphere. As a fluid regime of enormous Reynolds number and a wide variety of mechanisms of physical interaction, the atmosphere exhibits many modes of smaller-scale motion, ultimately leading to the "little whirls--lesser whirls and so on to viscosity," of the L. F. Richardson rhyme. Many of these energy degrading and dissipating modes are associated with the solid or liquid lower boundary of the Earth's atmosphere; others depend on the existence of more flexible, but still identifiable, internal boundaries of changing fluid properties, such as the tropopause, mesopause, inversion surfaces, and layers of the solar atmosphere. The presence or, occasionally, absence, of turbulence in these regions is of great importance to human activities (e.g., spread of air pollutants, evaporation from reservoirs and crops, beach erosion from ocean waves)

25. Washington, W.: "A Numerical Approach to Two- and Three-Dimensional Parallel-Plate Convection," presented at the 46th annual meeting of the American Geophysical Union, April 1965, Washington, D. C.

and to other sciences (e.g., turbulent interruption of astronomical observations, anomalous radio propagation).

Since there are no useful general solutions of turbulent flow equations, theoretical approaches to these problems are nearly as varied as the problems themselves. In some cases investigators have felt that the effect of the boundary on the flow was more important than the turbulence generated, so that laminar, or even inviscid, solutions were thought to be useful. In other cases empirical results from simple natural or laboratory-generated turbulent flows have been extrapolated to more complex flows or boundary conditions. Pure dimensional analysis has often led to successful predictions of the general behavior of a turbulent flow field. There is hope that computers in the future will be large and fast enough to generate useful solutions by "brute force" methods.

Boundary Layer Problems

Air-water interaction. To properly account for the transfer of heat, mass, and momentum to the atmosphere from the Earth, the nature of the interaction between air and a body of water must be better known. Laboratory study of these transfer processes contributes to basic aero-hydrodynamic knowledge and may be useful for better understanding of the atmosphere-sea exchange processes.

George Hidy's program of laboratory investigations has continued in collaboration with E. J. Plate (Colorado State University), using the wind-water tunnel at Colorado State University [26, 27]. So far, their experiments have confirmed the results of other investigators which deal with the relation between mean wind shear and the generation of waves and drift currents. In addition, it has been found that the growth of waves in the tunnel can be predicted reasonably well by

26. Hidy, G. M. and E. J. Plate: "On the Frequency Spectrum of Wind Generated Waves," Physics of Fluids 8, 1387-1389, 1965.

27. Hidy, G. M. and E. J. Plate: "Laboratory Studies of Wind Action on Water Standing in a Channel," Proceedings of the Sea-Air Interaction Conference, February 1965, Tallahassee, Florida; ESSA (USWB) Technical Note 9-SAIL-1, 1965.

estimating the amount of energy transfer to the water from the viscous air layer over the wavy surface. In particular, the shearing flow theory of J. W. Miles of the Geophysical Institute, University of California, San Diego, seems to be adequate for calculating the magnitude of energy transfer to the water.

The nature of the mean air motion in transition from flow over a smooth plate to a wavy surface has been examined. These results indicate how the surface stress changes with increasing aerodynamic roughness caused by the waves. The measurements are being placed within the framework of recent theoretical studies of A. A. Townsend of Cambridge University and others.

A striking feature of the combined air and water motion in the tunnel is presently being explored. Hidy and Plate have observed that waves grow more rapidly on water flowing against the wind, compared with the case of water initially standing in the tunnel. In contrast, waves grow less rapidly when water flows with the wind. This phenomenon has often been observed by oceanographers. It appears that these distinctive differences in wave growth are associated with the presence of shear in the water.

Further experiments in the CSU channel will be carried out during the coming year. These will center attention on (a) the character of the Reynolds stresses in the air near the water surface, (b) the details of the turbulent air flow at a constant height above the waves, and (c) the effect of the waves on heat and mass exchange between the two fluids.

The wind-water tunnel experiments are not designed specifically to model the mechanisms involved in atmosphere-sea interaction. Nevertheless, these experiments are continuing to shed considerable light on the physical processes involved in the coupling through a boundary layer of two fluids having widely differing densities and viscosities.

Laminar boundary layer on a rotating sphere. Edward Benton (on leave part of the year, with the University of Colorado) has been working on the classical but unsolved problem of the laminar boundary layer on a rotating sphere in an infinite undisturbed fluid. Previous theoretical studies of the steady-state solution of the problem, based upon the boundary layer approximation, have led to physically unacceptable conclusions. Mathematically, the difficulty is that of solving a coupled sixth-order nonlinear partial differential equation with two-point boundary conditions. Benton's approach is to obtain the steady-state solution by integrating the nonsteady equations for a sufficiently long time. In order to investigate how fast an impulsively started time-dependent solution approaches the steady state, Benton solved the well known von Kármán rotating disk problem as an impulsively started initial value problem and compared the time-dependent solution with the steady-state solution. The conclusion is that series expansions in suitable powers of time are indeed convergent, and the rate of convergence is sufficiently rapid. Consequently, the series solution can describe in considerable detail the transient flow throughout its approach to the steady state [28]. Application of the method to the rotating sphere is in progress, but the problem is, of course, vastly more difficult than for the disk because of the complicating effects of curvature. However, analytic approximations for the leading terms in series expansions in powers of time have been obtained [29].

Ekman flow instability. Experimental observations by A. Faller* of the University of Maryland have demonstrated the existence of an instability in the laminar Ekman flow in a rotating tank. Faller also argued

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* Faller, A. J.: "An Experimental Study of the Instability of the Laminar Ekman Boundary Layer," Journal of Fluid Mechanics 15, 560-576, 1963.

28. Benton, E. R.: "On the Flow Due to a Rotating Disk. Part I: Improved Steady-State Solution, Part II: Impulsively-Started Flow," NCAR PM No. 65-116, accepted for publication by the Journal of Fluid Mechanics.

29. Benton, E. R.: "Laminar Boundary Layer on an Impulsively Started Rotating Sphere," Journal of Fluid Mechanics 23, part 3, 611-623, 1965.

that the instability mechanism could lead to disturbances of importance in the atmospheric and oceanic planetary boundary layers. The stability problem, previously discussed by Faller, V. Barcilon* and others,** can be expressed in linear perturbation form, but analytic solutions are difficult. Lilly was able to solve numerically the eigenvalue perturbation equations and obtain stability and maximum growth rate criteria. The results compared favorably, in most respects, with experimental data, and also demonstrated certain inadequacies in the earlier experiments. They compared very well with more recent experiments and computations carried out simultaneously by Faller, using an initial-value time-integration method. As a result, it is believed that the instability mechanism observed in the laboratory experiments is now fairly well understood [30]. No further work is anticipated at this time on geophysical applications.

Boundary layer in a hurricane. A theoretical study of the hurricane boundary layer was made by Mariano Estoque (a summer visitor from the University of Hawaii). The problem was to compute values of three components of the velocity and the surface stress in hurricanes from the observed distributions of the surface pressure by integrating numerically the axially symmetric steady-state boundary layer equations.

Effects of stability on boundary layer heat flux. In the meantime, an entirely empirical approach has been taken by Deardorff to relate the

* Barcilon, V.: "Stability of a Non-Divergent Ekman Layer," Tellus 17, 53-68, 1965.

** Lilly, D. K.: "On the Computational Stability of Numerical Solutions of Time-Dependent Non-Linear Geophysical Fluid Dynamics Problems," Monthly Weather Review 93, No. 1, 11-26, 1965.

30. Lilly, D. K.: "Experimental Generation of Convectively Driven Vortices," Geofisica Internacional 5, 43-48, 1965.

turbulent heat flux above the lowest 50 m of the atmosphere to the mean potential temperature gradient and Richardson number. Data were used from the 1953 Great Plains turbulence observations, and from A. F. Bunker's (Woods Hole Oceanographic Institution) aircraft measurements of 1955 over the western Atlantic. The study was similar to a recent study by Tomio Asai (1965), in that the eddy coefficient for heat was related to stability rather than to height. However, a greater range of eddy coefficient, from 10^3 to 5×10^6 cm^2/sec, was found, and a small degree of counter-gradient heat flow was allowed. The results have been applied to NCAR's general circulation model.

Turbulence

The "direct-interaction approximation," developed by Robert H. Kraichnan during the last several years, is considered to be a new and powerful method in the theory of turbulence. Yet his method is not widely examined nor applied so far, probably in large part because of the difficulties associated with understanding it. Edward Benton has been studying Kraichnan's theory and delivered a series of four lectures in the NCAR Advanced Study Program during June, 1965. He is beginning to formulate the theory for the physically unrealistic but mathematically tractable model of turbulence proposed by Burgers in 1948. The aim is to gain insight by applying the theory to a case where exact solutions are available.

Walter Jones has also been concerned with the problem of turbulence, particularly the effect of buoyant stratification upon turbulence. Jones gave a series of three lectures on turbulence in the NCAR Advanced Study program in May, and attended the International Symposium on Fine Scale Structure in the Atmosphere held in Moscow in June, 1965. Turbulence on scales of between several hundred meters and several kilometers has the temporal characteristics of internal gravity waves. He is working on the question of whether this range of turbulence is a relatively efficient source for gravity waves, which in turn could represent an energy sink. The aim is to explain the minimum in the turbulence power spectra at frequencies just below the Väisälä frequency.

Oscillations in the Solar Atmosphere

The problem of small-scale motions in the solar atmosphere is being studied by Walter Jones. These motions appear to be at least quasi-oscillatory with periods of about 300 sec and with horizontal wavelengths of a few thousand kilometers. Existing explanations for these oscillations fall into two classes: (1) The excitation of motions near free modes of oscillation of the solar atmosphere produces greatly enhanced responses, as was long ago postulated for terrestrial atmospheric tides. (2) Excitation in an infinite isothermal atmosphere can produce resonance-like effects at natural frequencies. Lamb (1908) has shown such an effect at the acoustic cut-off frequency for a horizontally uniform forcing, while Moore and Spiegel (1964) have shown a similar result at the Väisälä frequency for a point source forcing. Jones showed that both of these are manifestations of the same general phenomenon. The infinite amplitude responses obtained through this phenomenon at exactly the critical frequencies are dependent on the atmosphere being both infinite and isothermal, however. Responses are still enhanced in the vicinity of such a resonance, but not as strongly as by other mechanisms. Jones has also investigated a special form of oscillatory motion in which there is no velocity divergence. These oscillations show a number of interesting properties: they are irrotational; fluid parcels have time-invariant thermodynamic states; and analytic solutions for the oscillations are readily obtained for atmospheres with complicated vertical temperature profiles. They possess a very simple dispersion relation between wavelength and frequency, one which is independent of atmospheric structure [31].

31. Jones, W. L.: "Generation of Small-Scale Oscillations in the Solar Atmosphere," NCAR PM No. 65-27, submitted for publication in the Astrophysical Journal.

CLOUD PHYSICS AND CONVECTION DYNAMICS

The clouds of the planet Earth are unique in the solar system. No other planet that we can see has this changing pageantry of clear blue skies, fog and stratus clouds, towering cumuli and thunderstorms, rain, snow, hail, tornadoes, and so forth. These varied processes by which the atmosphere eliminates its water vapor and returns it to the surface are the domain of cloud physics -- in which we include the effects of small particles as cloud nuclei, and some aspects of atmospheric electricity.

Cloud physics is related in an important way to the general circulation problem discussed in the preceding sections since, as we mentioned there, a large part of the flux of heat from the tropical oceans to the atmosphere is by means of condensing water vapor and the release of its latent heat. This takes place wherever it rains, and the heat is likely to be added to the atmosphere far away from the original source of the water vapor. It was mentioned specifically in the discussion of convection (p.88), that the aggregated effects of cumulus convection are being studied by every available means, particularly in the tropics where there is the most activity. This is an area where weather satellite observations are going to play a most important part, since they will cover a region of the world where observations are very sparse and where cloud pictures are of special value.

Cloud physics is also important in weather modification, particularly in rain and snow enhancement (or suppression) and the control of hail. The usual approach to this kind of weather modification is to seed with freezing nuclei in the anticipation that this will produce the desired results -- and under the right conditions it apparently does, to a certain degree. Atmospheric scientists are virtually unanimous in maintaining that such operations could be much more effective if the complex conditions leading to rain, snow, or hail could be better understood. Moreover, out of an effort to understand these atmospheric processes may come more powerful methods for weather modification than we can now even conceive.

CONDENSATION AND FREEZING NUCLEI

In perfectly clean air, with no dust or aerosol particles in it, water vapor does not begin to condense out spontaneously until a considerable degree of supersaturation has been attained -- the supersaturation depending on pressure and temperature. However, with particles in the air the water vapor can form a droplet around each particle at modest supersaturations, and some kinds of particles are much more effective than others. The ones in nature that are effective in initiating droplet formation at temperatures above freezing are referred to as "condensation nuclei," and their presence or absence plays an important role in warm cloud and rain formation.

When a cloud of water droplets is cooled below freezing the droplets do not necessarily begin to freeze, and may under special conditions remain liquid down to -40°C. However, when certain kinds of particles, known as "freezing nuclei," are in the air they can initiate freezing of the droplets at -5 or -10°C, and this change of a cloud from the liquid to the solid phase is often a crucial step in the formation of rain, snow, or hail.

The research at NCAR on both condensation and freezing nuclei is directed toward: (a) finding how such nuclei vary in the real atmosphere with time and place and altitude, and (b) understanding what they consist of and why they work the way they do. The first involves, to a large extent, field programs and the development of field measuring equipment, while the second is primarily a laboratory effort. One cannot be meaningful without the other.

Condensation Nuclei

While the physics of cloud formation is moderately well understood, there are large gaps in our knowledge. The continental sources of cloud condensation nuclei are not clearly established, and there is no agreement concerning the "accommodation coefficient for water," which affects the rate of droplet growth during the critical cloud forming process, and may exert some influence on cloud formation -- and eventually on the colloidal stability of clouds. The attempt to artificially influence this critical growth process by some means offers one approach to the problem of weather modification, and is part of the motive for these studies.

Measurements of the spectrum of critical supersaturations of condensation nuclei have been made by Patrick Squires near Boulder (using the NCAR aircraft) on the average of once a week since March 1965, from the surface to 25,000 ft with the purpose of establishing an approximate climatology of nuclei for Colorado. These measurements are being compared with the oceanic measurements of Sean Twomey (NRL and ESSA). Similar measurements were made by NCAR, and by the Colorado State University group using the same equipment, during the Hail Project of the summer of 1965.

In order to improve such measurements, Squires is developing apparatus for the rapid optical counting of cloud nuclei. In the field such a device can probably contribute to the study of the generation of nuclei by various natural surfaces. However, our present plans are to utilize it first in the laboratory: (a) to estimate the proportion of soluble material in natural nuclei, and perhaps to gain some insight into the nature of such soluble material, and (b) to study the effect (if any) of nuclei on the accommodation coefficient of water.

Freezing Nuclei

Effects of organic compounds on freezing water. Farn Parungo has continued her studies of nucleation of ice by organics. She found that terpenes held on siliceous support materials nucleated ice formation to some degree, but that their activity was generally increased by the presence of a trace of iodine. She also found that the differences in ice nucleative ability between pairs of optically active and racemic amino acids were closely related to the differences in heat of solution of the two forms. However, simple thermodynamic relationships between the nucleation temperatures of the individual amino acids have been sought in vain. It seems likely that the structural differences are sufficiently great to make the simple approach that was valid for the phenols and benzoic acids inappropriate in this series of compounds. The bulk of these findings were reported to the International Conference on Cloud Physics in Tokyo in May 1965 [32].

Generation of artificial freezing nuclei. In cooperation with Atmospherics, Inc., of California, experiments in seeding small cumulus clouds with "Weathercord" dropped from an aircraft completed the evaluation of this new explosive silver iodide generator. These preliminary tests, which apparently triggered the rapid growth of the seeded clouds and resulted in precipitation from relatively shallow clouds (4000 ft thick), are sufficiently interesting [33] to warrant the further larger scale testing which is already underway.

Distributions of natural freezing nuclei and the meteor hypothesis. A continuing program of sampling natural ice nuclei was carried out under the direction of Jan Rosinski in the form of three field test programs. The first one was located in Winter Park, Colorado, and consisted of determining natural ice nuclei concentration in air three times a day (0800, 1400, and 2000) for the period from January 15 to April 14, 1965. Concentration was determined by using the Bigg-Warner chamber. For this period, continuous integrated samples were collected and ice nuclei concentration was determined for three different cold chamber temperatures at the nearby Fraser (Colorado) Experimental Forest Station of the U. S. Department of Agriculture Forest Service. Mathematical analysis of these data has been started.

The second field test program consisted of sampling ice nuclei at

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32. Parungo, F. P. and J. P. Lodge, Jr.: "Molecular Structure and Ice Nucleation of Some Organics," Journal of the Atmospheric Sciences 22, 309-313, May 1965.

33. Goyer, G. G., L. O. Grant and T. J. Henderson: "The Laboratory and Field Evaluation of Weathercord, a New High Efficiency Cloud Seeding Device," NCAR Ms. No. 50, accepted for publication by the Journal of Applied Meteorology.

different altitudes and different positions relative to the jet stream core. Samples were collected for the period of December 1964 through May 1965. Sampling was performed on "Bowen rainfall anomaly" days and on dates between those periods.* At present, it appears that there may be an influx of ice nuclei from the stratosphere which could be associated with the action of a jet stream. These ice nuclei were found to persist for hours, sometimes for days, in the lower atmosphere. This result is contrary to our findings on the ice nuclei formed by evaporation of clouds which have a rather short life as ice nuclei. (The latter investigation will be emphasized during the field test program of summer, 1966.) A most important result of this program is the failure to find high concentrations of ice nuclei on many of the so-called "Bowen's days."

The third field test program was conducted in Bemidji, Minnesota, by J. Pierrard. Thirty-eight sampling flights by the NCAR aircraft were conducted during the period July 1 to August 5. Filter samples were taken for subsequent analysis of freezing nuclei populations aloft, at altitudes up to 29,000 ft. Approximately one-half the flights were vertical soundings in the Bemidji vicinity involving multiple filter samples each of about 300 liters of ambient air, at altitudes of 10, 15, 20, 23, 26, and 29 thousand feet mean sea level. The remainder of the of the flights included sampling in the vicinity of cumuli and several sample profiles at five altitudes between the surface and 15,000 feet mean sea level. Evaluation and analysis of the data from the freezing nuclei counts derived from the samples is under way.

Emphasis in the three programs is being placed upon finding the physical correlation between ice nuclei concentration and rainfall, in contrast to the statistical analyses performed by Keith Bigg (Australia) and others. The origin of the "pools" or "clouds" of ice nuclei is not

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*Dr. E. G. Bowen, C.S.I.R.O., distinguished Australian meteorologist, found strong evidence for excessive rainfall on certain calendar days when rainfall statistics from many stations and for many years were averaged. These days of anomalous rainfall were, according to Bowen, linked with certain well-known and reoccurring meteor showers.

yet being considered in this analysis. They were located in the atmosphere and their existence cannot be in doubt. If a relationship does exist between ice nuclei concentration and rainfall, a continuous measurement of ice nuclei concentration will give a better means of predicting the amount of rain (or snowfall) in the area where moisture-bearing air is mixed with air containing clouds of ice nuclei. The high ice nuclei concentrations associated with the jet stream appear to be present over very large distances. On a number of occasions when high concentrations of ice nuclei were recorded in Colorado, extremely heavy snowfall subsequently appeared in the central United States. Therefore, measurements made in Colorado or in adjacent states under clear sky conditions may be useful in the future for predicting unusually high precipitation downwind along jet streams.

The origin of some of the natural ice nuclei is still unknown, and the hypothesis that vaporizing meteors may provide one source still cannot be dismissed. Because of the lack of an ice nuclei sampling network, a statistical analysis has been started by Jan Rosinski to correlate rainfall anomalies with meteor shower activity. It differs from Bowen's analysis in that the correlation Rosinski is investigating is between meteor shower activity and precipitation over those particular areas where jet streams were present, since mixing of air from the stratosphere down into the rain-bearing level would be most likely there.

Techniques for determining atmospheric ice nuclei. Previous methods of ice nuclei detection, such as those developed by Keith Bigg in Australia, are not always reliable. Several papers, in addition to the NCAR work, have indicated various deficiencies in the analytical methods of detection. The greatest drawback of all methods, however, is that they cannot be used for continuous determination of ice nuclei concentration. An acoustical aerosol particle counter has been designed and built by Gerhard Langer [34]. It was adapted for continuous determination of ice nuclei concentration at any desired temperature. The

34. Langer, G.: "An Acoustic Particle Counter -- Preliminary Results," Journal of Colloid Science 20, 602-609, August 1965.

temperature spectrum of ice nuclei can also be determined by several such instruments operating at different temperatures. The detection is based upon growing the ice crystals on ice nuclei in a small cold chamber and then counting them with the acoustical particle counter. Tests were made with natural ice nuclei and also with silver idoide clouds. It was possible to follow a silver iodide plume over the ground and in the free air. This instrument, therefore, can also be used in diffusion studies to track an ice nuclei tracer and to determine its concentration instantaneously.

The progress in detection of ice nuclei permitted NCAR to start organizing a world-wide ground network for assessment of variations of ice nuclei. Ideally, stations should be located in areas where urban contamination is excluded. Stations established or under consideration, besides Boulder, are on Monte Cimone in Italy, in Kenya, on the Olympic Peninsula in Washington, and (next summer) in northeast Colorado.

FREEZING PROCESSES IN CLOUDS: HAIL FORMATION

Effects of Shock Waves on Freezing

Research has continued toward the understanding of the lightning discharge as a generator of shock waves, and of the effects of such shock waves on the freezing of super-cooled water droplets [35, 36]. Theoretical calculations of the decay of the shock waves generated by lightning discharges have been completed by Guy Goyer. The computer program yields shock overpressures as a function of distance of lightning channel temperature. Computed data cover the range of distance from 0 to 1000 ft and a range of temperature from 6,000 to 40,000°C. The results are in good agreement with single-point calculations obtained by others. In addition a theoretical analysis of the apparent

35. Goyer, G. G.: "Effects of Lightning on Hydrometeors," Nature 206, 1203, 1965.

36. Favreau, R. and G. G. Goyer: "The Effect of Shock Waves on a Hailstone Model," NCAR Ms. No. 110, accepted for publication by the Journal of Applied Meteorology.

relationship between rainfall and lightning has been published by Guy Goyer [37].

In the laboratory, a study was made by T. C. Bhadra of the inception of freezing of supercooled water by various physical methods. Bulk supercooled water was submitted to mechanical disturbances produced by sonic waves, shock waves, and violent stirring. In all cases where microbubbles of air were generated and grew in the bulk water, freezing occurred at temperatures warmer by a few degrees than the freezing temperature of the tranquil sample. The basic mechanism of the phenomenon, apparently closely related to the growth and motions of nascent air bubbles, is still under investigation. In addition, a thorough investigation of the physical parameters of the shock waves generated (by a bursting of diaphragms) in the shock tube used for these investigations has been completed by Bhadra.

Finally, Sonia Gitlin, after completing the necessary design and calibration of equipment, currently in progress, will study the freezing temperature of small supercooled water droplets submitted to mechanical disturbances. Supercooled droplets, either suspended in oil or on a sonic droplet holder developed by H. S. Fogler, will be submitted to sonic and/or shock waves of controlled intensity and frequency. This study is an attempt to reproduce and understand the field observations described below.

In the field, Guy Goyer gathered additional evidence at Yellowstone Park on the shattering and the freezing of supercooled droplets by shock-waves generated by cord explosives. The results show that shock-wave overpressures of the order of 0.1 psi are sufficient to produce these effects [38]. Attempts were also made, in cooperation with Charles Moore (of A. D. Little, Inc.), to reproduce lightning in supercooled clouds above Mt. Baldy in New Mexico by detonating 1000-ft lengths of

37. Goyer, G. G.: "The Effects of Lightning on Hydrometeors and Rainfall," in Proceedings of the International Conference on Cloud Physics, May-June 1965, Tokyo, Japan, 375-379.

38. Goyer, G. G.: "Mechanical Effects of a Simulated Lightning Discharge on the Water Droplets of 'Old Faithful' Geyser," Nature 206, 1302, 1965.

detonating cord. Radar recordings of these experiments are still under study.

<u>Studies of hailstones</u>. Even in northeastern Colorado, where hail is common in summer, there is considerable frustration involved in catching and studying fresh hailstones -- and some hazards as well. Very fresh hailstones are needed if one is to determine the liquid water content of hailstones and this accounts for the fact that such observations have never been made before.

Measurements of the liquid water content of fresh hailstones, attempted unsuccessfully the previous summer, were obtained on 15 samples during the summer of 1965. The calorimeter, designed and calibrated by Sonia Gitlin, and sensitive to 0.2 gram of liquid water in hailstones, was used successfully in the field, and samples from three storms in northeastern Colorado were analyzed. The results all indicate liquid water contents of less than 0.5 gram, or of less than 3% of the mass of the individual hailstones analyzed. A calorimetric method, devised by Goyer, where fresh hailstones are dyed with fluoresceine before being frozen for storage, was also tested. Slices of the dyed stones, exposed to ultraviolet light, show the location and extent of air channels in the stone. Analysis of several slices of stones from the same storms as those analyzed by Gitlin confirms her conclusions that the hailstones contained very little liquid water, if any. A publication, describing the calorimetric method is in preparation [39]. Further measurements throughout the hail season are planned for next year by Gitlin and Goyer.

<u>Particles in precipitation</u>. Determination of solid particle concentration and size distribution in different forms of precipitation is being continued. Snow, hail, and rain samples were analyzed. In some of the snow samples it was found that the particle size range 13 to 100 μ diameter was missing. Hail was collected from different storms and analyzed. In some of the hailstones there was a radial increase of

39. Gitlin, S., H. S. Fogler and G. G. Goyer: "A Calorimetric Method for Measuring the Liquid Water Content of Hailstones," submitted for publication in the <u>Journal of Applied Meteorology</u>.

particle concentration, and the spatial distribution of solid particles in certain hailstones revealed that they were oriented in the atmosphere during their growth. On the basis of these findings one might hope in the future to contribute to the following problems: time of growth of a hailstone, altitudes at which different layers of a hailstone are formed and, perhaps, a complete trajectory of a hailstone. It is already possible to deduce from the above analysis some of the environmental conditions under which a given hailstone was formed, as the stone was carried upward repeatedly in the violent currents of a thunderstorm.

Haze studies. J. Pierrard initiated studies of hazes. He is using thin-layer chromatography to resolve the chemistry of haze particles.

TECHNIQUES FOR OBSERVING CUMULUS MOTIONS

It is clear that a cumulus cloud includes strong upward (and downward) motions, and that these motions play a major part in many aspects of cloud physics. In the sections above on cumulus convection and thermal convection, some theoretical or empirical studies of convective motions were described. However, it has so far not been possible to observe in any detail the complex motions inside a large cumulus or a thunderstorm, and an understanding of them is particularly important in the study of hail. It could lead to methods of hail suppression, which is one of the motives for the cooperative field program being planned under National Science Foundation auspices for the summer of 1966.

Last year's Annual Report described preliminary efforts to design a dropsonde system to measure air motions in a cumulus cloud and, eventually, liquid water content as well. The dropsondes would be introduced from the above the cloud by high-flying aircraft. The dropsonde program continued in 1965 under the direction of Robert Bushnell [40] along three lines: sonde development, radar development, and wind tunnel tests.

40. Bushnell, R. H.: The NCAR Dropsonde Program, NCAR Technical Note TN-13, January 1966.

In August 1964 the first field operation of the M33 radar with the NCAR-29 indicator was finished at Ft. Lupton, Colorado, and the equipment was brought back to Boulder. In the course of efforts by the Facilities Division and the Sierra Research Corporation to incorporate certain design changes there were a number of delays and damage to the antenna in shipment, so no further operation of this radar has been possible in 1965.

A vertical wind tunnel was built for use in examining the accumulation of ice and water on sondes and for testing water content meters. This wind tunnel is mounted on a trailer and has a diesel generator so that the tunnel can be taken into the mountains where winter weather provides cold air. The tunnel was used, and some preliminary tests of the heater on the sonde pitot tube were made, under simulated icing conditions.

A laboratory model of a cloud droplet liquid water content meter was made as a beginning of work on such a meter design for use in the dropsonde. Special receivers were purchased for use in the dropsonde ground station. These receivers, which separate the signals from simultaneously falling dropsondes, were tested and used in the 1965 summer operations at New Raymer. Some circuits for the dropsonde tracker were tested for stability. (The tracker design is not complete; it has not yet been used in sondes.) Pressure meters were bought for use in calibrating dropsondes. The dropsonde design by Automation Industries was examined, the prototypes were tested, design changes were made, and a request was made for bids to produce ten such sondes with certain improvements. Vicon Instrument Company of Colorado Springs received the contract. In due course the sondes were delivered and four of them were used at New Raymer in the summer of 1965, though not dropped into storms. As part of this sonde procurement work we tested pressure transducers, tested transmitters and antenna radiation patterns, and examined further the design of the pitot tube using the vertical wind tunnel. A dispensing chute was designed for the Queen Air for dropping sondes by hand. This design was tested, along with tests of the sonde drag device, with drops of dummy sondes at the Marshall Field Site. Further tests were made of the drag opening mechanism. Because of failures in these tests, the opening mechanism was changed.

ATMOSPHERIC ELECTRICITY

The research program in atmospheric electricity is a study of the interrelationships between the development of electricity in the atmosphere and the growth of precipitation, a central problem in cloud physics. It is also concerned with electromagnetic emission from clouds as a measure of their electrical activity.

Discharges between Drops and Cloud Electrification

Paul Eden and Doyne Sartor have continued to analyze the 1964 aircraft observations [41] of radio emission from warm clouds made at Key West. Their analysis tends to support the data obtained during the summer of 1963, and indicates that there must exist a warm cloud electrification mechanism that produces intermittent microdischarges. However, the flight data from the 1964 operation are so poor that these radio emission observations are not entirely conclusive.

Pursuing this question in the laboratory, a discharge accompanied by the emission of light was repeatedly observed by Alan Miller just prior to the collison between two freely falling charged drops. Spectroscopic analysis of this emission by Miller, Claire Shelden and William Atkinson subsequently proved the electric discharge to be in the intervening air and not some luminous phenomenon of the water [42]. Further experiments by Atkinson and Miller showed the charge transfer between drops to take place in the order of nanoseconds or less (limited by the response of the detection instruments). Charge transfer is thus

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41. Eden, P. A. and J. D. Sartor: An Airplane-Mounted System for Sensing and Recording Radio Noise in Clouds, NCAR Technical Note TN-7, January 1966.

42. Miller, A. H., C. E. Shelden and W. R. Atkinson: "A Spectral Study of the Luminosity Produced during Coalescence of Oppositely Charged Falling Water Drops," NCAR Ms. No. 2, accepted for publication by the Physics of Fluids, 1965.

proven not to be limited, as has been supposed by most workers in the field, by the bulk relaxation time of water, i.e., approximately 10^{-4} to 10^{-6} sec, but is much faster. Theoretical analysis by Atkinson of a swarm of drop pairs discharging at random times gives a quasi-thermal electromagnetic emission spectrum extending up to at least 300 Mc, and possibly well into the microwave region, though the true relaxation time of water drops is still not determined. One of the significant advances in techniques which made this remarkable experiment possible has been the ability to produce and control water drops with sufficient regularity to use the integrated signal in a standard high-quality spectroscopic instrument [43].

John Latham (a visitor from the University of Manchester, England) has found Doyne Sartor's [44] 1954 prediction* of the effects of discharges between water drops and other free particles in an electrostatic field to be valid [45, 46, 47], and to follow the classical law of field enhancement between particles, as solved in general by M. H. Davis (of The RAND Corporation), who is cooperating informally with this program. These studies establish an important role for the electric-field drop-collision induction process in thunderstorm development [48]. Other

*Sartor, J. D.: "A Laboratory Investigation of Collision Efficiencies, Coalescence, and Electrical Charging of Simulated Cloud Droplets," Journal of Meteorology 11, 91-103, 1954.

43. Atkinson, W. R. and A. H. Miller: "Versatile Technique for the Production of Uniform Drops at a Constant Rate and Ejection Velocity," Review of Scientific Instruments 36, No. 6, 846-847, 1965.

44. Sartor, J. D.: "Induction Charging Thunderstorm Mechanism," in Problems of Atmospheric and Space Electricity, Elsevier Publishing Company, Amsterdam, 307-310, 1965.

45. Latham, J. and C. D. Stow: "Electrification Associated with the Evaporation of Ice," Journal of the Atmospheric Sciences 22, 320, 1965.

46. Latham, J.: "The Effect of Air Bubbles in Ice on Charge Transfer Produced by Asymmetric Rubbing," Journal of the Atmospheric Sciences 22, 325, 1965.

47. Latham, J., R. D. Mystrom and J. D. Sartor: "Charge Transfer between Model Ice Crystals Separated in an Electric Field," Nature 206, 1344, 1965.

48. Latham, J.: "The Convective Theory of Thunderstorm Electrification," Quarterly Journal of the Royal Meteorological Society 91, 369, 1965.

studies by Latham [see Refs. 45, 46, p.111] show a better agreement than had been obtained earlier between the theoretical thermal gradient charge-transfer process and the experimental work of E. J. Workman and S. E. Reynolds by taking into consideration the roughness of the particles [49, 50, 51, 52, and see Ref. 47, p.111].

A field investigation was conducted at Flagstaff, Arizona, in conjunction with Meteorology Research Incorporated of Pasadena, into selected electrical properties of clouds. Measurements were made of potential gradients and hydrometeor charges as a function of temperature, cloud particle size and concentration, liquid water content, and other parameters. Evidence was obtained for appreciable potential gradients within small cumulus clouds that did not yet contain precipitation, and for significant differences in electrical activity between seeded and unseeded clouds. The gradients must be related to the radio emissions from warm clouds described above. It is clear, however, that a definitive assessment of the relative efficacies of the various postulated charge generation (and discharging) mechanisms in producing cloud electrification must await the acquisition of much more accurate and detailed observations of the electrical properties of clouds than have hitherto been obtained. (For similar reasons the role of cloud electricity in the hydrometeor growth process requires further detailed studies of the electrification processes.)

Droplet Collisions and Hydrodynamic Interactions

With the help of Jack S. Miller of the Computing Facility, Doyne Sartor has extended the two-body viscous flow calculations of the drag

49. Latham, J. and C. D. Stow: "The Influence of Impact Velocity and Ice Specimen Geometry on the Charge Transfer Associated with Temperature Gradients in Ice," Quarterly Journal of the Royal Meteorological Society 91, 462, 1965.

50. Latham, J. and A. H. Miller, "Potential and Temperature Differences within Hot Pools in Yellowstone Park," Journal of the Meteorological Society of Japan 43, 175, 1965.

51. Latham, J. and A. H. Miller, "The Role of Ice Specimen Geometry and Impact Velocity in the Reynolds-Brook Theory of Thunderstorm Electrification," Journal of the Atmospheric Sciences 22, 505, 1965.

52. Latham, J. and A. H. Miller: "Some Electrical Phenomena in Yellowstone Park," in Fifth Yellowstone Field Research Expedition, 31, 103-111, 1965.

on two interacting spheres, first given by L. M. Hocking, to include more terms [53]. The results show a radical departure from Hocking when the spheres are close. As a consequence, finite collision efficiencies are found for droplets of less than 19 μ, whereas it had been previously accepted that there were virtually no droplet collisions at these smaller sizes. Similar results were obtained independently by M. H. Davis at The RAND Corporation.

A large tank of oil has been prepared and is being used to test the general hydrodynamic theory of the collision between two spheres. The idea here is that although the oil medium may not provide a direct modelling mechanism for cloud drops, it can be used as a specific test of the validity of the general theory of the interaction between two freely falling spheres. The drop trajectories observed in the laboratory experiments are compared with those obtained from computer computations using the general hydrodynamic theory for the interaction of two spheres and NCAR's extension of the Hocking solution, modified to incorporate the densities of the spheres and fluid, and the viscosity of the fluid appropriate to the model [54].

Large-Scale Atmospheric Electricity Correlations

An investigation has been undertaken by Doyne Sartor of the correlations between major solar flare activity, the atmospheric electric field at high altitudes, and "world wide" thunderstorm activity, to check the statistically significant correlations observed by Dr. Reinhold Reiter in the Bavarian Alps. Electric field and atmospheric conductivity measurements are being made at two locations in the Rockies: one a cooperative arrangement with Colorado State University on Chalk Mountain near Climax, the other a cooperative arrangement with the

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53. Sartor, J. D. and J. S. Miller: "Relative Cloud Droplet Trajectory Computations," in Proceedings of the International Conference on Cloud Physics, May-June 1965, Tokyo, Japan, 108-112.

54. Sartor, J. D.: "Summary-Outline of Extended Computations and Observations of Cloud Drop Collisions Including Electrical Effects," presented at the AMS Conference on Cloud Physics and Severe Local Storms, October 1965, Reno, Nevada.

Arctic and Alpine Institute of the University of Colorado for the use of their 13,000 ft Niwot Ridge installation. On Niwot Ridge NCAR provides a wind generator for power and a telemetry link from the mountain station to the NCAR laboratory. The standard weather elements of temperature, wind speed, and wind direction are recorded; in addition, solar cells are provided for identifying cloudy and blowing snow conditions, to indicate when the electric field is disturbed by local storms or drifting snow. These data are shared with the University of Colorado and with Douglas Lilly's program for studying the mountain waves and the chinook winds. After many blown-down wind chargers and snow-clogged instruments, the station is now working reliably.

Doyne Sartor has applied NCAR's experience with droplet coalescence to an effort on the Hawaiian Island of Maui to "milk" the warm clouds of moisture in usable quantities for the Park Service ranger station. Upon studying the problem of catching cloud drops with a screen, it was found that the efficiency was so small that the application of an electric field could possibly increase the screen's collision efficiency significantly. The project has reached the installation phase, using a charged screen up-wind and a grounded screen behind. We plan to continue our pursuit of this project during the Hawaiian monsoon season next year.

Research toward increasing precipitation is under way under Bureau of Reclamation auspices at the South Dakota School of Mines, directed by Richard A. Schleusener. This work is being aided by NCAR's Atmospheric Electricity Program, which has installed electric field measuring equipment on the South Dakota School of Mines aircraft; a 50 Mc noise receiver has also been installed to study radio emission prior to the aircraft's entry into the cloud, and to examine the effects on the radio antenna of impacts of precipitation particles following entry [see Ref. 41, p.110].

PHYSICS OF ICE CRYSTALS

Water-vapor-ice phase changes in the atmosphere are a central problem of cloud physics. Virtually everything that happens in crystallization and nucleation is conditioned by what "goes on" at the interfaces between the various phases of water. The unifying theme of Charles Knight's work is the study of this fundamental problem.

Charles Knight and his wife, Nancy, spent the first half of 1965 at the University of Hokkaido, Japan, and the second half at NCAR. While in Japan, work on the growth of ice polycrystals from water was terminated. The results will be useful in the interpretation of hailstone crystal orientations, but they have no bearing upon the nature of interfaces [55]. Work on "negative crystals" occupied most of Knight's time prior to his return, and was reported at the International Conference on Cloud Physics in Tokyo [56]. Negative crystals are holes within a parent crystal (in this case, ice), bounded by crystallographic faces of the parent. A method was invented for growing negative crystals by evaporation through a hypodermic needle embedded in the ice, and work was done on negative crystal growth habit as a function of temperature (in other words, evaporation rates of different ice crystal faces as a function of temperature). The apparatus used at Hokkaido was not good enough to give quantitative results, and some time was spent at NCAR designing and building a better set-up. This is a fairly long-range experimental project and, if successful, the final results will be: (1) relative evaporation rates of basal and prism faces as a function of pressure and temperature, from 0 to -40°C; (2) direct determination of the equilibrium form of ice from 0 to about -20°C; and (3) various further experiments using the very perfect faces of the negative crystals, such as contact angle measurements. The evaporation rate results are of direct importance to the problem of snow crystal growth, and all three should add to the knowledge of ice crystal surfaces.

55. Knight, C.: "Grain Boundary Migration and Other Processes in the Formation of Ice Sheets on Water," accepted for publication by the Journal of Applied Physics.

56. Knight, C. and N. Knight: "'Negative' Crystals in Ice: A Method for Growth," Science 150, 1819, 1965.

In the negative crystal work one needs to start with large ice crystals rather free from imperfections. Attempts have been made at NCAR to grow ice crystals of the required perfection. These have not succeeded, and have evolved into an investigation of the origin of imperfections in growth from the melt. Knight plans to get ice crystals from the Mendenhall Glacier in Alaska for his further work on negative crystals.

Other work in Charles Knight's program in 1965: (1) A book on crystal growth was completed [57]. (2) Work on curved dendritic growth and spherulites continued. New ideas are being tested, but the end is not in sight. (3) A new etching technique, suitable for measuring crystal orientations in hailstones, has been invented and nearly perfected. (4) Some work was done (and will be continued next summer) by Knight in conjunction with James Benedict of the Arctic and Alpine Research Institute, University of Colorado, on the origin of the ice in ice-cored moraines in the Rocky Mountains. NCAR's part is to try to get evidence from crystal textures on whether these are remnants of past glaciers. (5) Nancy Knight has been working on the effect (if any) of hydrogen peroxide upon nucleation of supercooled water. This is exploratory work, and is being done because of the unique relations between H_2O_2 and H_2O, and because H_2O_2 is produced in water by various kinds of radiation and by ultrasonic waves, and might be responsible for the fact that some of these phenomena affect nucleation temperature.

57. Knight, C.: The Freezing of Supercooled Liquids, D. Van Nostrand Co., Princeton, New Jersey, in press.

LIFE CYCLES OF TRACE GASES AND AEROSOLS

TRACE GASES

Water vapor is such an important and evident trace gas in our atmosphere that we forget that it is indeed present in only trace amounts. Carbon dioxide is a trace gas in the Earth's atmosphere (about 0.03% by volume) but apparently is a major constituent in the atmospheres of Mars and Venus. Methane and ammonia, also trace gases on Earth, are rather abundant on the major planets. Ozone exists in our stratosphere in measurable quantities, but probably scarcely exists at all on the other planets. All these gases are polyatomic, and they are effective absorbers of radiation, both infrared and ultraviolet. This feature of these gases allows them to play an important role -- far out of proportion to their relative amounts -- in the radiative balance of all the planetary atmospheres, and their distributions in an atmosphere must therefore be taken into consideration in any study of the dynamics or motions of an atmosphere.

In the case of the terrestrial atmosphere there is another motive for studying the distributions of these trace gases: they can sometimes be used as _tracers_, and the atmospheric motions and the rates of exchange of air between regions of the atmosphere -- and between atmosphere and surface -- can often be best determined by studying their distributions. In fact, most of what we know about certain features of atmospheric exchange comes from such studies of trace gas distributions, both radioactive and stable, coupled with a knowledge of their sources and sinks [58].

The question of air pollution is now such a "cause célèbre" that it is hardly necessary to mention our general concern with the chemistry of the air over our big cities. It seems unlikely that meteorologists and atmospheric chemists will ever be able to control or stop air

58. Martell, E. A.: "Upper Atmosphere Composition," review article in _1966 Yearbook of Science and Technology_, McGraw-Hill, New York.

pollution -- this must probably be done by eliminating the sources -- but they can predict this evil and document it when it does occur.

All three of these aspects of the chemistry of trace gases motivate NCAR's atmospheric chemistry program. A major part of the program is concerned with developing and applying techniques for measuring these trace constituents in the field. Another part of the program, less extensive but very important, involves the chemical and photochemical reaction studies that can be performed in the laboratory. We will discuss the former first.

Observations of Trace Gases in the Atmosphere

Development of techniques. The field of atmospheric chemistry, as it is now practiced, is restricted not so much by the natural bounds of the subject as by what it is currently impossible to measure. With the possible exception of the polluted air near cities, factories, and the like, the atmospheric chemical changes and reactions which we study occur at such low concentrations that it has been virtually impossible to determine accurately the strengths of chemical sources and sinks and to measure steady-state concentrations. Consequently, except for a few very favorable cases, all our information on the subject tends to be indirect, and the few direct measurements which have been made could well be seriously in error without anyone being able readily to prove or disprove them.

Furthermore, the atmosphere is large and diverse, so if measurements are to lead to useful generalizations concerning the chemistry of the atmosphere they must be made repeatedly over a very large range in both space and time. To date, since the subject of atmospheric chemistry is still relatively unexplored, studies and observations of composition have been quite fragmentary. This dictates that methods of measurements must be as inexpensive as possible, consistent with the necessary accuracy, and that the methods be sufficiently simple that a number of people may use them.

The above considerations have been paramount in shaping the part of NCAR's program in atmospheric chemistry that is devoted to observing trace gases in the atmosphere. Primary consideration has been given to the development, evaluation, adaptation, and proof of simple and direct chemical methods of observation. A secondary concern has been to identify a small number of "loose ends" in previous research and to devote the necessary effort to tidying these up.

One of the major problems of gas sampling in the field is the definition of the volume of gas sampled. James Lodge, John Pate, Blair Ammons, and Glenda Swanson have perfected a technique, using inexpensive hypodermic needles as critical orifices, which permits very accurate control of flow rates, and also permits taking a number of simultaneous samples [59].

Lodge and his colleagues have now also nearly completed evaluation of a new design for the bubbler which brings the sampled air into contact with a chemical reagent. This design is competitive in price with the previous all-glass bubblers, but is far less liable to breakage. The design is the result of collaboration between John Pate, Arthur Wartburg, and Blair Ammons.

Our understanding of the chemistry involved in determining sulfur dioxide (SO_2) concentration by the Schiff reaction is now almost complete. John Pate and Blair Ammons are completing a study which matches very well with one made by U. S. Public Health Service personnel at the R. A. Taft Sanitary Engineering Center in Cincinnati; the two techniques complement one another excellently, and should, between them, lead finally to the establishment of a truly standard method. Work on the collection of sulfur dioxide on chemically impregnated dry filters had to be put aside temporarily in favor of the studies described above. However, these studies have led to a better understanding of the previous

59. Lodge, J. P., Jr. J. B. Pate, B. E. Ammons and G. A. Swanson: "The Use of Hypodermic Needles as Critical Orifices in Air Sampling," NCAR Ms. No. 19, presented at the annual meeting of the Air Pollution Control Association, June 1965, Toronto, Canada; accepted for publication by the Journal of the Air Pollution Control Association.

data and should make the remaining experiments on this technique much easier and more meaningful.

The return of Arthur Wartburg to James Lodge's staff made it possible to reactivate the project to develop a simple chemical carbon dioxide analyzer. This development is now 90% complete. Components of the system are being used at sensitivities higher than those for which they were designed; however, the outlook is now hopeful. In any case, the work should be completed within the next few months.

Although Jitendra V. Dave's work will be described in more detail in the major section on Atmospheric Radiation (below), it should be noted here that a most powerful technique for observing atmospheric ozone has been by measuring the absorbed and scattered sunlight in the ultraviolet. This approach has been used for many years from the ground, and occasionally from balloons and satellites, but now Dave and Paul M. Furukawa, with Carlton L. Mateer (a visitor from the Meteorological Service of Canada), have worked out the details of a technique for making worldwide measurements of ozone distribution from a satellite. A proposal for such an experiment has been submitted to NASA by Dave.

ENCAR rocket sampler. The final design and fabrication of the ENCAR Sampler ("ENclosed Cryopump for Air sample Recovery"), for very high altitude sampling, being carried out under NASA Research Contract NASr-224, was delayed in order to carry out experimental work to obtain essential heat transfer data. Concurrently a computer program was carried out to evaluate a spectrum of heat exchanger configurations, refrigerants, air sampling rates, etc., using the NCAR Computing Facility. This work is completed, and the final details of the ENCAR Sampler design are now being worked out. Fabrication of two samplers and their engineering tests and experimental evaluation will be carried out during the next six to nine months. The first two Aerobee-150 rocket sampling flights, for collection of air samples and radioactive aerosols in the upper stratosphere and mesosphere, are tentatively scheduled for the latter half of 1966 at White Sands, New Mexico.

Field studies of trace gases. In atmospheric science the end use of analytical methods is application in the field. For this reason, the Atmospheric Chemistry Group undertakes a number of field studies which serve the threefold purpose of uncovering any individual problems with analytical methods, demonstrating their applicability, and providing data of real geochemical interest.

The largest single involvement in 1965 was a collaborative study with the U. S. Army Tropic Test Center of the trace composition of the tropical atmosphere in and around the Canal Zone. Surprisingly enough, there have been almost no studies anywhere in the world on the subject of the atmospheric chemistry of the tropics. A pilot visit to the Canal Zone during February 1965 yielded several days of sampling. The group consisted of John Pate, Arthur Wartburg, Evelyn Frank, and James Lodge. Blair Ammons subsequently assisted in the reduction of the data. Samples were taken for a wide variety of gaseous and particulate species during an extended period of north wind. The data spanned too short a period to be considered as necessarily typical, and the conditions under which the samples were taken did not completely exclude the possibility that some of the measured substances originated in human activities along the Canal. A few measurements must be made at far more remote sites, using battery-powered collection equipment. February is the driest month in the Canal Zone. Pate visited the Zone again in November, which is the wettest month. Data reduction is not yet complete on the more recent samples, but qualitatively none of the measurements seem to be in serious disagreement with the previous ones. The experiment of truly remote sampling was not possible during this period, but will be undertaken in February 1966, when a large group will again visit the Canal Zone.

Briefly, the following tentative conclusions have been drawn from the data, more as a model to suggest further tests than as a firm finding: The most prevalent purely chemical corrosive agent in the atmosphere is salt. Somewhat soluble calcium compounds were also present in a rather constant concentration. Sulfuric acid droplets, which are ubiquitous in the temperate atmosphere, were not present in the air coming off the Atlantic, but were added to surface air during its passage over the Isthmus. The trace gas concentrations are consistent with the idea that anaerobic bacterial activity takes place at some depth in the soil, and that the gaseous metabolites are then partially oxidized by organisms in the surface layers. Thus, for example, hydrogen sulfide appears to be absent, but sulfur dioxide is present, as is formaldehyde. Generally speaking, the substances present above the forest canopy appear to be in still more highly oxidized states, consistent with the notion that the final oxidation to end products is photochemical.

Methane, molecular hydrogen, and water vapor. Arnold E. Bainbridge has made considerable progress in the investigation of the distribution of atmospheric methane (CH_4) and molecular hydrogen by air sample collection and gas chromatographic analysis [60, 61]. Analysis of samples collected by W. L. Dowd (former UCAR Fellow from the University of California at San Diego) aboard the Scripps Institute of Oceanography ship Argo between 30°N and 30°S over the eastern Pacific Ocean indicates variations in CH_4 and H_2 concentration of surface air with latitude. Vertical profile sample collections in balloon flights from Palestine, Texas, in March and July 1965 showed a marked decrease in methane concentration with altitude above the tropopause. Other experiments show that various soils serve as sources and sinks for H_2 and CH_4. NCAR aircraft sampling flights, and improvements in sampling instrumentation and gas chromatographic instrumentation, are in progress.

Dieter H. Ehhalt (a visitor from the University of Heidelberg) has

60. Bainbridge, A. E.: "Determination of Natural Tritium," accepted for publication by the Review of Scientific Instruments.

61. Bainbrdige, A. E.: "On the Methane in the Troposphere and Lower Stratosphere," NCAR Ms. No. 38, presented at the CACR Symposium, August 1965, Visby, Sweden; accepted for publication by Tellus.

initiated a study of the variations of the isotopic composition of precipitation and water vapor with season and altitude, by low level tritium counting and D/H determination by mass spectrometry [62, 63]. A quantitative water vapor collector has been developed for collection of water vapor profiles with the NCAR aircraft. Analyses of initial collections over continental and ocean areas are in progress.

After the return of Hans Dütsch to the University of Zurich last spring, Irving Blifford supervised the program and the regular balloon ozonesonde ascents were continued by Peter Crooimans. During the summer of 1965 Dütsch returned from Switzerland to assemble for publication [64] all the ozonesonde data obtained at Boulder. The ozonesonde observation program was transferred to the Facilities Division in November 1965, and it is hoped that the measurements can be continued for at least another year, possibly with the support of the Air Force.

Studies of Photochemical Reactions

When the vertical distribution and atmospheric chemistry of methane (CH_4) are better understood, it may be an excellent tracer for the motion of masses of air originating in the stratosphere and mesosphere. The reaction of atomic oxygen with methane may be the principal "sink" for methane in the stratosphere. Therefore, the study of this reaction [65] has been continued by Richard Cadle and Eric Allen [66] . Data

62. Ehhalt, D. and K. Knott: "Kinetische Isotopentrennung bei der Verdampfung von Wasser," Tellus 17, 389, 1965.

63. Ehhalt, D.: "Tritium and Deuterium in Atmospheric Hydrogen," NCAR Ms. No. 39, presented at the CACR Symposium, August 1965, Visby, Sweden; accepted for publication by Tellus.

64. Dütsch, H. U.: Ozonesonde Flights Flown from Boulder August 1963-August 1965, NCAR Technical Note TN-10, January 1966.

65. Allen, E. R., F. E. Grahek and R. D. Cadle: "Scanning Photomultiplier for Studying Chemiluminescent Reactions in Flow Systems," Review of Scientific Instruments 36, 35-37, January 1965.

66. Cadle, R. D. and E. R. Allen: "Kinetics of the Reaction of $O(^3P)$ with Methane in Oxygen, Nitrogen, and Argon-Oxygen Mixtures," Journal of Physical Chemistry 69, 1611-1615, 1965.

obtained in the laboratory have been used to calculate the rates of methane removal at various altitudes. The calculations demonstrate that at between 40 and 70 km the O + CH_4 reaction must greatly deplete the atmosphere of methane. This result is especially interesting in view of measurements of the vertical methane concentration profile made by the NCAR Isotope Geophysics Program. These measurements have demonstrated in a preliminary way that the methane mixing ratio decreases rapidly with increasing altitude above the tropopause. A major product of the reaction of atomic oxygen with methane in the presence of molecular oxygen has been found to be formaldehyde, which therefore must be produced in the stratosphere and mesosphere [67]. Hydrogen was also found among the products of this reaction, and laboratory experiments are now being made in an attempt to find the relative amounts produced at various levels in the atmosphere.

Cadle and Allen are supplementing their study of the atomic oxygen-methane reaction by an investigation of the atomic oxygen-butane (C_4H_{10}) reaction, since some features of such reactions can be determined more accurately with butane than with methane (though butane is a much rarer gas in the atmosphere).

John W. Powers (from Ripon College, a visiting scientist for a year) undertook investigations of the reactions of atomic oxygen with sulfur dioxide (SO_2) and with acetaldehyde (CH_3CHO). Both of these reactions occur in photochemical smog, and the former may also contribute to the formation of the "sulfate layer" discovered by C. Junge and his co-workers in the stratosphere.* Calculations using the results of the laboratory measurements and values for oxygen atom concentrations estimated by Julius London showed that any sulfur dioxide reaching the stratosphere would be rapidly converted to sulfur trioxide (SO_3). The

* Junge, C. E.: Air Chemistry and Radioactivity, Academic Press, New York, 1963.

67. Allen, E. R. and R. D. Cadle: "A Study of the Effect of Molecular Oxygen on Atomic Oxygen--Hydrocarbon Reactions," accepted for publication by Photochemistry and Photobiology.

latter would in turn rapidly react with any water vapor present to form a sulfuric acid aerosol.

Methylene (CH_2) is produced by nuclear explosions in the atmosphere and may play a major role in atmospheric tritium chemistry. Because of the interest in methylene chemistry in the NCAR Isotope Geophysics Program, Richard Cadle undertook a laboratory investigation to determine whether methylene reacts with nitrogen. Methylene was produced by the photochemical decomposition of a mixture of ketene and nitrogen, and the products were analyzed by infrared spectroscopy. There was no indication of the formation of nitrogen-containing compounds, so the reaction of methylene with nitrogen must be very slow if it occurs at all.

Reactions of the vapor of alkali and alkaline earth metals, such as Na, Cs, Li, K, Ca, and Mg, with atomic oxygen occur in the D-region. They are important in determining the steady-state concentrations of the free metals. Furthermore, the reactions may lead to ionization (chemionization) and contribute to the electron content of the D-region. Essentially, no investigations of such reactions have been made in the laboratory until now, and such a study is being initiated by Keith Schofield. In particular, he will investigate reaction rates and products, and the extent of ionization, if any.

Because of the interest of several NCAR programs in sulfates in the atmosphere, Richard Cadle stopped over in Hawaii while returning from a trip to Japan and sampled particles in the fume from the Halemaumau crater of Kilauea volcano. Most of the collected material was found to be a supersaturated solution of ammonium sulfate. No chloride or elemental sulfur was found. There can be no doubt that the fume originally contained sulfate, but contamination of such samples by atmospheric ammonia is very difficult to prevent, and further studies, especially by the NCAR Atmospheric Chemistry Program, will be made to confirm and extend this isolated result. It suggests that at times large amounts of ammonium sulfate may be emitted into the atmosphere by volcanic eruptions.

Concentrations of excited, $O(^1D)$, atomic oxygen in the atmosphere below 100 km have been recalculated as a function of altitude by Richard Cadle. The recalculation was necessary because of very recent revisions upward (by about two orders of magnitude!) in the estimated value for the collisional de-excitation coefficient for $O(^1D)$. The new estimates for $O(^1D)$ concentrations are so low that it is unlikely that excited atomic oxygen contributes to an appreciable extent to the formation of any species below 100 km, with the possible exception of excited molecular oxygen, $O_2(^1\Sigma_g^+)$. This seems to eliminate the possibility which has often been suggested that atmospheric nitrous oxide (N_2O) is produced by the reaction of $O(^1D)$ with nitrogen, and leaves bacterial action in the soil as the most likely source of nitrous oxide.

Miles LaHue, under the direction of James Lodge, has continued his study of the photochemistry of gaseous terpenes, specifically as it may affect aerosol formation in the ambient atmosphere from these natural plant products. The problem has proved more difficult than was originally anticipated, but some recent breakthroughs suggest that a few more months will suffice to complete the present phase of this study. It is not yet clear whether there will prove to be sufficiently characteristic chemical products to permit a simple diagnosis of the reaction in the open atmosphere. However, the study should at the very least constitute a contribution to the general field of photochemistry.

AEROSOLS

Like the trace gases, aerosols are of interest to atmospheric scientists because they affect the radiation balance, they can serve as atmospheric tracers (especially the radioactive aerosols from nuclear tests), and they are an obvious and disagreeable component of atmospheric pollutants. Moreover, as described at some length in the section on Cloud Physics, certain aerosols act as condensation nuclei and others act as freezing nuclei, and these are most important factors in cloud physics.

The sources and sinks of aerosols are a major source of concern, and a considerable mystery still in some cases. We have already mentioned the possible significance of meteoritic dust from the top of the atmosphere; other sources are the Earth's surface, volcanoes, industry, the oceans, decaying matter, and the formation of aerosols in the free atmosphere by coalescence of both organic and inorganic materials. This last is perhaps the most important of all and the least well understood.

Still another aspect of aerosols in the atmosphere is the part they play as catalytic agents in promoting certain photochemical reactions. This may be most significant in the production of organic smog of the sort for which Los Angeles is noted [68].

Observations of Non-Radioactive Aerosols in the Atmosphere

Julian P. Shedlovsky has obtained preliminary data on the chemical composition of aerosols in the lower stratosphere [69]. Collections were made using ultra-clean polystyrene filters on high altitude aircraft, with operational support provided by the Air Weather Service. The samples were subjected to neutron activation, radiochemical separation and gamma-ray spectrometry for determination of S, Na, Cr, Mn, Fe, Co, Cu and Au. Similar studies of tropospheric aerosol profiles are being initiated with NCAR aircraft support. A first successful rocket flight under NASA "Project Luster" was carried out from White Sands in November 1965. The impactor prepared by Shedlovsky for this flight will be subjected to electron microscope and chemical analysis.

Irving H. Blifford, Jr., who joined the Isotope Geochemistry Program in April 1965, has initiated a study of tropospheric aerosols by use of impactors flown on the NCAR aircraft. Preliminary results obtained by profile collections up to 10 km in oceanic and continental

68. Cadle, R. D.: Particle Size, Reinhold Publishing Corp., New York, 1965.

69. Shedlovsky, J. P. and S. Paisley: "On the Meteoritic Component of Stratospheric Aerosols," NCAR Ms. No. 41, presented at the CACR Symposium, August 1965, Visby, Sweden; accepted for publication by Tellus.

environments are being evaluated. Impactor and filter collections of tropospheric aerosols will be studied by means of optical microscopy and X-ray fluorescence analysis.

There have been several reports of difficulty in using the apparently very simple method of James Lodge and Kanwal J. Parbhakar* for determining the sulfate content of fine particles. It now appears that Evelyn Frank has found the reason for the reported difficulty, which is not inherent in the chemistry; if field experience supports her laboratory findings, a short note explaining the necessary changes in procedure will be written [70].

A number of materials have been examined by Frank to determine the possibility that they can be mistaken in appearance for sulfuric acid droplets as seen under the electron microscope. No other substance has been found which even remotely resembles the appearance of sulfuric acid droplets. It has previously been reported that numerous samples taken in both continental and marine air near the surface contained droplets identical in appearance with laboratory samples of sulfuric acid, as revealed by the electron microscope. Communication with Prof. Dr. Christian Junge at the University of Mainz elicited the statement that fully three-fourths of the particles which he collected by balloons at approximately 20 km altitude also resembled sulfuric acid, as do micrographs by Robert Soberman (Air Force Cambridge Research Laboratories) of noctilucent cloud particles collected by rockets at about 80 km. (However, this last point is open to more argument, and Soberman tends to disagree with this interpretation.) Meanwhile, studies at NCAR by Edward Martell suggest that sulfuric acid droplets compose a significant fraction of the total Aitken nuclei population of the

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* Lodge, J. P., Jr. and K. J. Parbhkar: "An Improved Method for the Detection and Estimation of Micron-Sized Sulfate Particles," Analytica Chimica Acta 29, 372-374, 1963.

70. Lodge, J. P., Jr. and E. R. Frank: "An Improved Method for the Detection and Estimation of Micron-Sized Sulfate Particles: Correction," NCAR Ms. No. 100, accepted for publication by Analytica Chimica Acta.

atmosphere. Accordingly, a single sample was taken near the Eldora Ski Area, near Boulder. Once again, it is dangerous to make inferences from a single sample, but nearly two-thirds of the particles present were apparently sulfate, ranging from almost pure sulfuric acid to almost pure ammonium sulfate. The balance appeared to be combustion products of one sort or another. The total concentration was approximately 300 particles/cc in the sampled air. More volatile particles would not have been detected by the method used, so that the presence of additional terpenoidal particles was neither proved nor disproved. Subsequent samples will be taken with simultaneous determination of condensation nuclei concentrations. The work has been carried out primarily by Evelyn Frank and James Lodge, with some collaboration from William Fischer, Gladys Sturdy, and Mark Ryan. Marine samples were collected aboard a boat belonging to Alexander Goetz.

The development of a laser system by Guy Goyer and Robert Watson is described in more detail under Atmospheric Radiation, but it is important to note here that this has already been demonstrated as a powerful tool for ranging the aerosol layers in the troposphere and stratosphere. The tests of this system at Sacramento Peak, New Mexico, in the summer of 1965 were successful and proved its effectiveness. Some of the preliminary results of this experiment, in which cloud and dust layers were detected at altitudes above 10 km, are mentioned below.

Radioactive Aerosol Tracer Studies

Experimental measurements of Ce^{144} and Sr^{90} in air samples have been continued since March 1964 by Edward A. Martell and Charles A. Watkins. The results show large seasonal variations in the Ce^{144}/Sr^{90} ratio during the present moratorium on atmospheric nuclear tests. These and related measurements are being evaluated in relation to seasonal and annual variations in the stratosphere-troposphere exchange process [71, 72].

Irving Blifford has initiated a computer analysis of surface air radioactivity data obtained from the 80th meridian network during the IGY. (He had been instrumental in obtaining these data while he was still with the Naval Research Laboratory.) About two-thirds of the available data have been put on punched cards and magnetic tape. Some preliminary results have been obtained from power spectral analysis, cross spectral analysis and in terms of empirical orthogonal functions for selected 80th meridian locations. It is planned to extend the analysis of these radioactivity data from the point of view of large scale turbulence and exchange processes.

Coagulation and Growth of Aerosols

A large fraction of the aerosol particles in the atmosphere falls into a class in which the ratio of the mean free path of the suspending medium (λ) to the particle radius (R) is the order of unity. In this regime the dynamics and the mechanisms for growth of particles are not fully understood, because the aero-thermodynamics of particle bahavior here lie neither within the applicability of continuum theory nor within the realm of the classical kinetic theory of gases. To interpret how natural aerosols behave, the physical chemistry of aerosols in the transition regime where $\lambda/R \sim 1$ must be better known. As a contribution to this area of study, a program to investigate the growth of aerosols by coagulation has been undertaken in the laboratory.

71. Martell, E. A., J. P. Shedlovsky and C. A. Watkins: "Radiochemical Evidence for Antler Shot Contribution to the September 1961 Fallout," Journal of Geophysical Research 70, 1295, 1965.

72. Martell, E. A.: "The Size Distribution and Interaction of Radioactive and Natural Aerosols in the Stratosphere," NCAR Ms. No. 40, presented at the CACR Symposium, August 1965, Visby, Sweden; accepted for publication by Tellus.

Recent theoretical work by Astakhov (USSR),* J. R. Brock (a visitor from the University of Texas) and George Hidy [73, 74, 75] on the mechanism of coagulation of aerosols in the transition regime has predicted certain conditions for the growth rates of clouds of particles. Since these results deal with idealized spherical particles subjected to Brownian motion, only in a crude way do they take account of the effects of electrostatic charging, external fields of force, non-uniformities in the suspending gas, and surface chemistry. Nevertheless, before further theoretical improvements can be made, the results of the idealized models should be tested experimentally. Coagulation studies have been begun by Paul Brown in a cylindrical chamber of 500 ℓ volume. Measurements of the coagulation rate, as estimated by the decay of the concentration of particles per unit volume, will be taken over a range of temperature and pressure of 20 to 60°C, and 2 to 0.001 atm. In addition to measuring the reduction in the total number concentration, changes in time of the size distribution of the aerosols will be estimated by sampling through a Goetz aerosol spectrometer.

Progress in these experiments is hindered by the difficulty of introducing a suitable aerosol cloud into the chamber at reduced pressure. Paul Brown is presently trying to solve this key problem before proceeding with the coagulation studies.

In addition to the above studies of growth by coagulation of aerosols, investigations are continuing into certain features of the size distribution of natural aerosols. Hidy is searching for a more complete

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* Astakhov, A. V.: "The Rate of Brownian Coagulation of Aerosols in the Thirteen-Moment Approximation," Doklady Akademii Nauk SSSR 161, 1114-1117, 1965.

73. Brock, J. R. and G. M. Hidy: "Collision Rate Theory and the Coagulation of Free-Molecule Aerosols," Journal of Applied Physics 36, 1857-1862, 1965.

74. Hidy, G. M. and J. R. Brock: "Some Remarks about the Coagulation of Aerosol Particles by Brownian Motion," Journal of Colloid Science 20, 477-491, 1965.

75. Hidy, G. M.: "On the Theory of the Coagulation of Non-Interacting Particles in Brownian Motion," Journal of Colloid Science 20, 123-144, 1965.

explanation for the so called "self-preserving" size spectra in natural aerosols. Numerical calculations have been successful in predicting the "self-preserving" behavior in idealized clouds whose particles are in Brownian motion [76, 77]. These computations are being continued to include more complicated collisional mechanisms, and to incorporate growth by condensation.

Hidy's original calculations used a model for the discrete aerosol spectrum. This method turned out to be somewhat limited for studying size spectra of very polydisperse aerosols. A technique has recently been developed by E. X. Berry (Desert Research Institute) to integrate numerically the coagulation equations over a much wider range of size. We hope to use Berry's scheme to extend our calculations.

The studies of the growth of small particles by condensation and coagulation may also be useful to a new, sophisticated numerical cloud model presently being designed by Douglas Lilly (see p.88). Part of the work on aerosol-cloud particle-size spectra is expected to be aimed at providing information for Lilly's dynamical computations.

Aerosol Scavenging in the Troposphere

Many questions concerning the lifetimes of aerosols center on the efficiency with which raindrops scavenge airborne particles. A series of experiments was completed by Jan Rosinski to determine the details of capture of particles in the 1 to 50 μ diameter size range by a spherical object under conditions corresponding to free-falling raindrops of from 0.5 to 3.0 mm diameter. This covers particle capture by a sphere in the Reynolds number range 137-860. The analytical phase of this study by John Pierrard involves computation of particle trajectories using a flow field model based on a match between boundary-layer flow

76. Hidy, G. M.: "Modeling Growth Processes for Particles in Clouds," in Proceedings of the International Conference on Cloud Physics, May-June 1965, Tokyo, Japan, 92-96.

77. Hidy, G. M. and D. K. Lilly: "Solutions to the Equations for the Kinetics of Coagulation," Journal of Colloid Science 20, 867-874, 1965.

near the sphere and potential flow in the far field. (This work is related to the work of Doyne Sartor, on the collision of droplets, described in the section on Droplet Collisions and Hydrodynamic Interactions, p.113.)

ATMOSPHERIC RADIATION

Reference has been made in the preceding sections to the role of radiation in determining the heat budget of the atmosphere, as a means for measuring the distributions of trace gases and aerosols, as a technique for observing conditions in an atmosphere from above, etc. The mathematical problems involved in calculating radiative transfer through an absorbing atmosphere are formidable: in the infrared part of the spectrum molecules absorb in a complex way (their spectra are made up of many absorption lines); and in the ultraviolet the phenomenon of scattering by molecules (Rayleigh scattering) with absorption requires that one take into account multiple scattering. The effects of clouds, dust, and haze are even more difficult to deal with, since the optical properties of aerosols are not very well known and the scattering by such particles (Mie scattering) poses a staggering analytic problem. For some purposes empirical or approximate calculations of radiative transfer and absorption are adequate, but there are many applications for which this is not good enough.

OPTICAL DETERMINATION OF OZONE DISTRIBUTION

One application where refined observational and analytical techniques are required is the determination of the distribution of atmospheric ozone by observing the scattering and absorption of solar ultraviolet radiation, either from the ground (the so-called Umkehr effect, for example) or from a satellite. This is an area that warrants more effort, since understanding of the role of atmospheric ozone in stratospheric circulation studies, in photochemical and radiative-transfer processes, and in the upper atmospheric radiative energy budget has been somewhat limited by both the lack of detailed theoretical knowledge of the effects of ozone absorption, and by insufficient observational data on the spatial and time variations in the distributions of ozone. The efforts of Jitendra V. Dave, Claire E. Shelden and Paul M. Furukawa have been oriented to help alleviate this situation.

Dave and Furukawa made an extensive theoretical-numerical study of the radiative transfer of the primary and multiply-scattered solar radiation for a plane-parallel, nonhomogeneous Rayleigh atmosphere [78]. An average ozone distribution for middle latitudes was assumed. The products of this study were the following: First, the computed radiation parameters were used to study the effects of scattering (primary and higher orders) and of ground reflection on the energy absorbed by ozone. While scattering has relatively little effect on the total energy absorbed by ozone in a unit column, it was shown that it does significantly change the distribution of the absorbed energy within the column. The effect of ground reflection is appreciable in determining both the total amount of energy absorbed within a unit column and its vertical distribution.

Second, since the computed values of the intensity, polarization and fluxes are required in various studies (e.g., rocket and satellite experiments, astronomical observations, etc.), the results were put into tabular form and are being published as an American Meteorological Society Meteorological Monograph under the joint sponsorship of NCAR and AMS [79].

Finally, the results of the theoretical-numerical work have led to a feasibility study of determining the total amount and the vertical distribution of ozone from satellite measurements of the solar radiation diffusely reflected by the Earth's atmosphere [80]. This study was a combined effort with a summer visitor at NCAR, Carlton Mateer , who used the computed values of the radiation intensities to test an inversion technique for obtaining information on the vertical distribution of ozone from the backscattered radiation.

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78. Dave, J. V. and P. M. Furukawa: "Intensity and Polarization Characteristics of the Radiation Emerging from an Optically-Thick Rayleigh Atmosphere," NCAR Ms. No. 65, submitted for publication in the Journal of the Optical Society of America.

79. Dave., J. V. and P. M. Furukawa: "Scattered Radiation in the Ozone Absorption Bands at Selected Levels of a Terrestrial, Rayleigh Atmosphere," Meteorological Monographs 7, No. 29, American Meteorological Society, Boston, January 1966

80. Dave, J. V. and C. L. Mateer: "The Determination of Ozone Parameters from Measurements of the Radiation Backscattered by the Earth's Atmosphere," NCAR Ms. No. 107, submitted for publication in the Journal of the Atmospheric Sciences.

As a result of this study a proposal for determining the spatial distribution of ozone from measurements of the backscattered radiation has been submitted to NASA jointly by J. V. Dave (Principal Investigator) and Dr. Donald F. Heath, Goddard Space Flight Center, NASA (Co-Investigator). The program is being proposed for a future Nimbus satellite (Nimbus "D," scheduled to be flown in 1969), and will include further theoretical-numerical studies as well as additional experiments.

The method of successively evaluating the higher orders of scattering used in the above-mentioned ozone problem was also applied by Dave, Furukawa and W. Hugh Walker, of the NCAR Computing Facility, to a plane-parallel, non-absorbing, Rayleigh atmosphere [81]. The characteristics of the radiation diffusely reflected and transmitted by such an atmosphere were studied extensively for scattering optical thickness between 1.0 and 10.1. The computer program developed for this study was later used to supply Thomas Gehrels (The Lunar and Planetary Laboratory, University of Arizona) with numerical data to assist him in interpreting his spectral polarization measurements of the poles of Jupiter.

Dave also participated with another visiting scientist at NCAR, Robert S. Fraser (Thompson-Ramo-Woolridge Systems Corporation, Redondo Beach, California) in the latter's study of the effects of Fresnel reflection on the scattered radiation emerging from a non-absorbing, Rayleigh atmosphere. Two possible bases for cooperation for the coming years were explored, namely, to study (1) the effects of Fresnel reflection on the diffuse radiation in the presence of ozone absorption, and (2) the effects of large particle scattering on the upward radiation emerging from the atmosphere.

81. Dave, J. V. and W. H. Walker: "Convergence of the Iterative Solution of the Auxiliary Equations for Rayleigh Scattering," submitted for publication in the Astrophysical Journal.

The design and development of a double monochromator for the purpose of determining instantaneously the vertical distribution of ozone from a ground-based station has been continuing under the guidance of Claire Shelden. The mechanical design of the monochromator is essentially completed and work on the pointing control and grating rotator should be completed by June 1966; some mechanical construction has been completed, and all but one casting for the monochromator casing have been received. Much of the past and current effort is being directed at general investigations of the various characteristics and components associated with the instrument. The experience and information gained from these investigations have been shared with other groups at NCAR for their special optical problems, and also with Donald F. Heath of NASA to assist him in determining the instrumental specifications for the proposed satellite experiment mentioned above.

INFRARED RADIATIVE TRANSFER

The subject of infrared radiative transfer in the atmosphere has received some attention by the dynamic meteorologists, since the cooling and heating of the atmosphere by emission and absorption of water vapor, clouds, and dust layers must be taken into account in any complete numerical model of the general circulation. One approach is to make use of the observations of infrared radiation flux that have been made from balloons (radiometersondes).

Donald Johnson (a summer visitor from the University of Wisconsin) worked on the effects of instrumental errors of the Suomi-Kuhn radiometersonde system on the downward, upward, net and equivalent radiative flux computations. The normal distribution for the random radiative flux errors was justified so that firm confidence intervals can be made for individual radiative flux estimates. Filtering techniques to reduce the effect of the random error component were studied. The effects of random temperature sensor errors on filtered estimates of the downward, upward, net and equivalent radiative flux, as well as infrared cooling, were also determined.

LASER SYSTEM FOR AEROSOL OBSERVATIONS

The theoretical study on the detection of atmospheric aerosols by the measurements of the intensity of back-scattered laser radiation has been completed and published by Robert Watson and Guy Goyer [82]. The detection of optically thin suspensions of aerosols in the Earth's atmosphere by high powered laser systems has been shown to be feasible. The basic theory of incoherent or independent scattering applies, and the scattering coefficients have been calculated by use of the Mie theory for various aerosol size distributions. In the stratosphere, for average concentrations of aerosols, and for a power law distribution of exponent 3.5, 88% of the scattering intensity is due to molecules; for an exponent of 3.0, 75% can be attributed to molecular scattering. Thus only a small contribution from the aerosols would be expected on the basis of an average profile. However, the concentrations appear quite variable on a short term basis, and stratified layers with aerosol concentrations greater than the average can be detected with the high spatial resolution of the laser.

Since a crucial factor in such a theoretical analysis is the ratio of molecular to aerosol scattering, the possible non-linearities in Rayleigh scattering by molecules have been investigated in the laboratory by Robert Watson and Maynard Clark [83]. The experiment was designed to investigate the angular distribution of scattered radiation in a nitrogen atmosphere using an unfocussed single giant ruby laser pulse of 20 nanosec duration and 10 Mw peak power. No noticeable changes were detected in the scattering pattern predicted by Rayleigh scattering theory or in the polarization of the incident beam. Moreover, the depolarization factor for nitrogen, obtained in this experiment, 0.032, is in reasonable agreement with previously measured values 0.021 to 0.036.

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82. Watson, R. D. and G. G. Goyer: "On the Detection of Atmospheric Aerosols Using a Ruby Laser Source," in Proceedings of the Conference on Atmospheric Limitations to Optical Propagation, March 1965, Boulder, Colorado, 444-453.

83. Watson, R. D. and M. K. Clark: "Rayleigh Scattering of 6943 Å Laser Radiation in a Nitrogen Atmosphere," Physical Review Letters 14, 1057, 1965.

The laser optical probe system designed and assembled by Watson and Clark, was tested on Sacramento Peak, New Mexico, during the last summer. A large number of photographs of return signals have been gathered and are being analyzed. Under good seeing conditions, pulse repetition rates of 15/min were used to monitor the temporal changes in the aerosol layers as detected by the laser probe. Preliminary analysis of last summer's data leads to two tentative conclusions: First, the determination of range (altitude), thickness, and number of layers of high altitude cirrus clouds invisible to the eye at night is possible with a high degree of precision. The large magnitude of the return signals from such clouds at altitudes above 10 km is such as to permit temporal and spatial analysis of their fine structure in very great detail. Second, dust layers above 10 km are only detectable through a very thorough reduction of the data and a detailed analysis of the slope of the oscilloscope traces. In spite of difficulties in the receiving system, usable data on the scattering cross section and altitudes of atmospheric scatterers should be obtained. The reduction of the data is not sufficiently advanced to permit a discussion of the results at this time. Work is continuing to reduce the data and to improve the performance of the receiving system.

SPECIAL PROJECTS

ANALYTICAL SERVICES: RAINWATER ANALYSIS

As a part of the Atmospheric Chemistry Program under James Lodge, a semi-autonomous group consisting of Allan Lazrus and Kathleen Hill has been performing extensive chemical analyses of rainwater. Its primary mission is the operation of a network of approximately 35 stations at which rainwater samples are collected and subsequently analyzed in the laboratory for mineral content. A number of new analytical methods have been developed by Lazrus, particularly one for sulfate, which is almost a classical problem. These automatic methods make it possible to handle a current analytical load with less than half of the staff that would be necessary for manual chemical analysis. This group will soon be able to handle additional types of studies, and will be able to perform analytical services for other groups at NCAR and elsewhere.

AIRBORNE TURBULENCE MEASUREMENT PLATFORM

An investigation has been conducted to determine the feasibility of an airborne system for measuring air motions on the order of 10 to 20 cm/sec for periods of over 100 sec. In the past, airborne instrumentation was not available to measure the long-wavelength portion of the turbulence spectrum accurately, although this portion probably contains most of the turbulent energy and fluxes and accounts for a large part of the heat, moisture, and momentum above the surface boundary layer of the atmosphere. Donald Lenschow has determined that such a system is now technically feasible, and he is obtaining the necessary components. Basically, an inertially stabilized platform will be used as a reference for measuring airplane accelerations and attitude angles, and a stabilized gust probe mounted on a boom on the front of the airplane will measure the velocity of the air with respect to the airplane. This system will be used to measure velocity spectra, and the fluxes of heat, momentum, water vapor and turbulent energy. It should also be useful for studies of local wind phenomena, such as airflow over mountains and sea breezes, as well as motions in and around clouds.

MISCELLANEOUS

The principal effort in the miscellaneous category is a study of a group of related phenomena which apparently demonstrate a rather profound modification of the structure of liquid water by very small amounts of electromagnetic energy at low frequencies. Since the entire field of cloud physics is concerned with the physical behavior of water in all its phases, it appeared that the fragmentary reports in the literature should be investigated, tied together to the extent possible; and, if the effect proved to be real, enough work should be done to derive a coherent theory of the phenomenon with some predictive value. Investigators here are William Fischer, Gladys Sturdy, Ann Pugh, and Mark Ryan. They claim to have clearly demonstrated that minute energy inputs in the radio frequency range modify liquid water structure sufficiently to affect ice nucleation, viscosity, electrolytic conductivity, and the electrophoretic mobility of suspended particles. Recent findings also suggest the possibility of an effect on coalescence phenomena in water. Data are being obtained on the frequency dependence of the effect, and a preliminary paper has been published in Nature.* It seems that one more year will suffice to demonstrate at least the main features of the effect, if indeed it does exist.

George Hidy is continuing his study of a proposed atmospheric simulation chamber. This work is more fully reported under the Advanced Studies Program, under whose aegis the study is being pursued.

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*Fischer, W. H. and R. Perdue: "Shock Induced Freezing of Activated Supercooled Water," Nature 204, No. 4960, 764-765, 1964.

LABORATORY OF ATMOSPHERIC SCIENCES STAFF, 1965

Director
William W. Kellogg

Assistant to the Director
William L. Jones

Scientists

Allen, Eric R.
Anderson, David N. (transferred to HAO 1 April 1965)
Atkinson, William R.
Bainbridge, Arnold E.
Benton, Edward R. (leave of absence from September 1965)
Bhadra, Tarani C. (to 16 July 1965)
Blifford, Irving H., Jr.
Brown, John A., Jr.
Bushnell, Robert H.
Cadle, Richard D.
Dave, Jitendra V.
Deardorff, James W.
Durney, Bernard (transferred to HAO 1 April 1965)
Dütsch, Hans U. (to 26 March 1965)
Fischer, William H.
Goetz, Alexander
Goyer, Guy G.
Hidy, George M.
Houghton, David D.
Jones, Walter L.
Julian, Paul R.
Kasahara, Akira
Knight, Charles A.
Langer, Gerhard
Lenschow, Donald H. (from 27 September 1965)
Lilly, Douglas K.
Lodge, James P., Jr.
Martell, Edward A.
Nakagawa, Yoshinari (transferred to HAO 1 April 1965)
Newton, Chester W.
Parungo, Farn P.
Pate, John B.
Pierrard, John M.
Plooster, Myron N.
Rosinski, Jan
Sartor, J. Doyne
Schofield, Keith (from 2 August 1965)
Shedlovsky, Julian P.
Squires, Patrick

van de Boogaard, Henry M. E.
van Loon, Harry
Washington, Warren M.

Assistant Scientists

Bagley, Kent W.
Bravo A., Humberto (leave of absence from 1 August 1965)
Brown, Paul M.
Chaffee, Margaret A. (to 17 December 1965)
Emmanuel, Marion B.
Freed, Michele W. (to 17 September 1965)
Furukawa, Paul M.
Gitlin, Sonia N.
Glover, Vincent M.
Haagenson, Philip L. (from 14 June 1965)
Kimball, Dean F. (to 31 March 1965)
LaHue, Miles
Lazrus, Allen L.
Miller, Alan H.
Nagamoto, Clarence T.
Parbhakar, Kanwal (to 15 September 1965)
Pierrard, Helen (to 30 April 1965)
Ryan, Mark E.
Sheesley, David C. (leave of absence until 1 May 1965)
Shelden, Claire E., Jr.
Sturdy, Gladys E.
Wartburg, Arthur F.
Watkins, Charles A.
Watson, Robert D. (leave of absence from 1 September 1965)
Willis, Glen E.

Engineers

Chu, Raymond D. (from 16 September 1965)
Clark, Maynard K. (to 11 June 1965)
Denton, Edward H.
Gerrish, Samuel (from 4 January 1965 to 20 August 1965)
Glaser, Walter C.

Visiting Scientists
(long-term)

Asai, Tomio (Meteorological Research Institute, Tokyo; from 1 October 1964 to 1 October 1966)

Ehhalt, Dieter (University of Heidelberg; from 1 September 1964 to 1 September 1966; transferred from ASP 1 September 1965)

Eichenberger, Eduard (Federal Institute of Technology, Zurich; from 24 August 1964 to 20 July 1965)

Hiei, Eijiro (Tokyo Astronomy Observatory, Japan; from September 1964 to September 1965; transferred to HAO 1 April 1965)

Latham, John (Department of Physics, Manchester College of Science and Technology, Manchester, England; from 1 December 1964 to 15 December 1965)

Powers, Jack W. (Department of Chemistry, Ripon College, Wisconsin; from 20 August 1964 to 20 August 1965)

Söderberg, Bengt (Royal Swedish Air Force, Barkarby, Sweden; from 1 September 1964 to 28 February 1966)

Yun, Kwang-Sik (National Research Council of Canada, Ontario; from 27 December 1965 to 27 December 1967)

Visiting Scientists
(short-term)

Baer, Ferdinand (Colorado State University; from 15 July 1965 to 15 August 1965)

Bates, Fred C. (St. Louis University; from 3 September 1965 to 13 September 1965)

Clarke, R. H. (Division of Meteorological Physics, CSIRO, Victoria, Australia; from 1 October 1965 to 29 October 1965)

Dütsch, Hans U. (Federal Technical University, Zurich; from 5 August 1965 to 17 September 1965)

Fraser, Robert S. (TRW Space Technology Laboratories, Redondo Beach, California; from 11 October 1965 to 22 October 1965 and from 13 December 1965 to 17 December 1965)

Fritts, Harold (University of Arizona; from 14 July 1965 to 31 July 1965)

Mateer, Carlton L. (Meteorology Branch, Department of Transport, Toronto; from 12 July 1965 to 13 August 1965)

Pallmann, Albert J. (St. Louis University; from 3 August 1965 to 15 September 1965)

Preining, Othmar (First Institute of Physics, University of Vienna; from 15 May 1965 to 15 September 1965)

Sekera, Zdenek (Department of Meteorology, UCLA, Los Angeles; from 1 August 1965 to 31 August 1965)

Telford, James W. (Division of Radiophysics, CSIRO, Sydney, Australia; from 14 June 1965 to 24 June 1965 and from 2 July 1965 to 8 July 1965)

Visiting Students

Bunting, J. Graham (Manchester College of Science and Technology, Manchester, England; from 1 July 1965 to 31 August 1965)
Culberson, Helen R. (University of Colorado; from 23 September 1965)
Dodge, James C. (University of Colorado; from 23 September 1965)
Downen, Douglas (St. Louis University; from 3 August 1965 to 15 September 1965)
Evans, Howard (Colorado State University; from 9 June 1965 to October 1965)
Friesen, Richard B. (University of Colorado; from 7 June 1965)
George, John (University of Colorado; from 4 June 1965)
Liggett, William (Stanford University; from 15 June 1965 to September 1965)
Lowery, Michael (Beloit College, Wisconsin; from 4 January 1965 to April 1965)
Mehollin, Elaine (Beloit College, Wisconsin; from 30 December 1965 to April 1965)
Robin, James E., Jr. (University of Colorado; from 22 June 1964)
Schreck, Roger (Kansas State Teachers College; from 8 June 1965 to September 1965)
Wu, Shi-Tsan (University of Colorado; from 2 September 1964 to 1 April 1965; transferred to HAO)

Research Assistants and Technicians

Abbott, Charles E.
Ammons, Blair E.
Booton, William D.
Catlin, Charles C.
Coleman, Ralph L.
Corless, Gary B.
Dolan, Gerald J.
Eden, Paul A.
Frank, Evelyn R.
Garhart, Charles H.
Gibson, Adrian D.
Grahek, Frank E. (on leave from 15 September 1964 to 1 June 1965)
Grotewold, Walter
Hallenbeck, George A. (to 30 November 1965)
Heidt, Leroy E. W.
Johnston, Linda A. (from 15 November 1965)
Jordan, Placido
Knight, Nancy
Kovacs, Stephen W.
Lai, Juey-Rong (from 26 April 1965)
Leyner, Carol J. (transferred to Facilities 5 April 1965)
Lin, San S. (from 4 October 1965)
Lohndorf, Fred L. (transferred to HAO 1 April 1965)
Loraas, Judith A. (to 26 February 1965)

Lueb, Richard A.
Marshall, Robert C. (transferred to Facilities 15 October 1965)
McElhaney, Lawrence J.
McKay, Dale B. (from 27 January 1965 to 15 October 1965; transferred to Facilities)
Meadows, Lindalu (from 1 February 1965 to 1 June 1965)
Mystrom, Richard (from 1 February 1965 to 4 June 1965)
Nasser, Benny E., Jr.
Neary, Michael P. (to 5 November 1965)
Nimitz, Suzanne P. (from 15 February 1965 to 19 November 1965)
Nowroozhaddad, George (to 13 April 1965)
Paluch, Ilga R. (from 17 November 1965)
Perdue, C. Robert (to 9 July 1965)
Pollock, Walter H. (from 24 November 1965)
Pugh, R. Ann
Roberts, Clara M. (to 4 June 1965)
Robin, James E., Jr.
Scharberg, Mary Jo
Seiller, Nancy M. (from 16 September 1965)
Shafer, Betsy (from 1 February 1965 to 31 May 1965)
Smith, Jean F.
Stevenson, Patricia R. (from 1 July 1965 to 13 August 1965)
Swanson, Glenda (to 31 May 1965)
Tussy, Dennis L.
Underwood, Kathleen C. (from 15 June 1965)
von Krogh, Joan E. (from 19 May 1965 to 15 October 1965; transferred to Facilities)
Weber, James R. (from 22 December 1965)
Wood, Janet (from 1 June 1965 to 20 August 1965)
Wright, Eyvonne M. (to 30 June 1965)

Office Staff

Allen, Mary (to 31 May 1965)
Coombs, Joy (to 13 July 1965)
Elsea, Virginia (to 24 August 1965)
Gordon, Mary C. (leave of absence from 18 June 1965 to 15 September 1965)
Hatt, Kathleen L. (from 15 September 1965)
Hieke, Ursula I. (transferred to Facilities 15 March 1965)
Johnstone, Margaret
Kobl, Christine (from 14 June 1965)
Leach, Mary H. (to 31 December 1965)
Lowndes, Gayle F.
Nelson, Bonnie C. (from 1 June 1965 to 31 August 1965)
Plywaski, Louise (to 15 April 1965)
Ross, Maxine F. (from 25 March 1965)
Sahm, Linda G.
Scott, Anne T.
Stroh, Jane C. (from 2 June 1965)
Teter, Joyce L.

Tillman, Carol S.
van Dusen, Lois A. (transferred from Administration 1 August 1965)
Whitson, Dorothy (transferred to HAO 1 April 1965)

LABORATORY OF ATMOSPHERIC SCIENCES PUBLICATIONS, 1965

Allen, E. R.: "Quantitative Gas Chromatographic Sampler for Static Gaseous Reaction Systems," accepted for publication by Analytical Chemistry.

______ and R. D. Cadle: "A Study of the Effect of Molecular Oxygen on Atomic Oxygen--Hydrocarbon Reactions," accepted for publication by Photochemistry and Photobiology.

______, F. E. Grahek and R. D. Cadle: "Scanning Photomultiplier for Studying Chemiluminescent Reactions in Flow Systems," Review of Scientific Instruments 36, 35-37, January 1965.

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______: "On the Methane in the Troposphere and Lower Stratosphere," NCAR Ms. No. 38, presented at the CACR Symposium, August 1965, Visby, Sweden; accepted for publication by Tellus.

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Blifford, I. H.: "Factors Affecting the Performance of Commercial Interference Filters," accepted for publication by Applied Optics.

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Cressy, P. J. and J. P. Shedlovsky: "Cosmogenic Radionuclides in the Bondoc Meteorite," Science 148, 1716, 1965.

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______ and P. M. Furukawa: "Intensity and Polarization Characteristics of the Radiation Emerging from an Optically-Thick Rayleigh Atmosphere," NCAR Ms. No. 65, submitted for publication in the Journal of the Optical Society of America.

______ and ______: "Scattered Radiation in the Ozone Absorption Bands at Selected Levels of a Terrestrial, Rayleigh Atmosphere," Meteorological Monographs 7, No. 29, American Meteorological Society, Boston, January 1966.

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______ and W. H. Walker: "Convergence of the Iterative Solution of the Auxiliary Equations for Rayleigh Scattering," submitted for publication in the Astrophysical Journal.

Deardorff, J. W.: "Gravitational Instability between Horizontal Plates with Shear," Physics of Fluids 8, 1027-1030, June 1965.

______: "A Numerical Study of Pseudo Three-Dimensional Parallel-Plate Convection," Journal of the Atmospheric Sciences 22, 419-435, July 1965.

______ and G. E. Willis: "The Effect of Two-Dimensionality on the Suppression of Thermal Turbulence," Journal of Fluid Mechanics 23, part 2, 337-353, 1965.

Dütsch, H. U.: Ozonesonde Flights Flown from Boulder August 1963-August 1965, NCAR Technical Note TN-10, January 1966.

Eden, P. A. and J. D. Sartor: An Airplane-Mounted System for Sensing and Recording Radio Noise in Clouds, NCAR Technical Note TN-7, 1966.

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______ and K. Knott: "Kinetische Isotopentrennung bei der Verdampfung von Wasser," Tellus 17, 389, 1965.

______, R. Kosiek and R. Pfeiffer: "Zum Kernphotoeffekt am Ar^{40} und Ar^{38}," Zeitschrift fuer Physik 187, 210, 1965.

Fankhauser, J. C. and C. W. Newton: "The Migration of Thunderstorms as Related to Wind and to Moisture Supply," Weatherwise 18, 68-73, April 1965.

Favreau, R. and G. G. Goyer: "The Effect of Shock Waves on a Hailstone Model," NCAR Ms. No. 110, accepted for publication by the Journal of Applied Meteorology.

Fischer, W. H.: "The Radio Noise Spectrum from E.L.F. to E.H.F.," Journal of Atmospheric and Terrestrial Physics 27, 475-480, 1965.

Fjørtoft, R. and B. Söderberg: "A Prediction Experiment with Filtered Equations," NCAR Ms. No. 59, a preliminary report.

Frank, E. R. and J. P. Lodge, Jr.: "Characterization of Polystyrene Fibers," NCAR Ms. No. 71, accepted for publication by the Journal de Microscopie.

Gitlin, S., H. S. Fogler and G. G. Goyer: "A Calorimetric Method for Measuring the Liquid Water Content of Hailstones," submitted for publication in the Journal of Applied Meteorology.

Goetz, A.: "The Constitution of Aerocolloidal Particulates above the Ocean Surface," in Proceedings of the International Conference on Cloud Physics, May-June 1965, Tokyo, Japan, 42-45.

Goyer, G. G.: "Effects of Lightning on Hydrometeors," Nature 206, 1203, 1965.

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______, T. C. Bhadra and S. Gitlin: "Shock Induced Freezing of Supercooled Water," Journal of Applied Meteorology 4, 156-160, February 1965.

______, L. O. Grant and T. J. Henderson: "The Laboratory and Field Evaluation of Weathercord, a New High Efficiency Cloud Seeding Device," NCAR Ms. No. 50, accepted for publication by the Journal of Applied Meteorology.

Hidy, G. M.: "On the Theory of the Coagulation of Non-Interacting Particles in Brownian Motion," Journal of Colloid Science 20, 123-144, 1965.

______: "Modeling Growth Processes for Particles in Clouds," in Proceedings of the International Conference on Cloud Physics, May-June 1965, Tokyo, Japan, 92-96.

______ and J. R. Brock: "Some Remarks about the Coagulation of Aerosol Particles by Brownian Motion," Journal of Colloid Science 20, 477-491, 1965.

______ and D. K. Lilly: "Solutions to the Equations for the Kinetics of Coagulation," Journal of Colloid Science 20, 867-874, 1965.

______ and E. J. Plate: "On the Frequency Spectrum of Wind Generated Waves," Physics of Fluids 8, 1387-1389, 1965.

______ and ______: "Laboratory Studies of Wind Action on Water Standing in a Channel," Proceedings of the Sea-Air Interaction Conference, February 1965, Tallahassee, Florida; ESSA (USWB) Technical Note 9-SAIL-1, 1965.

Houghton, D.: "A Quasi-Lagrangian Study of the Barotropic Jet Stream," Journal of the Atmospheric Sciences 22, 518-528, 1965.

______, A. Kasahara and W. Washington: "Long-Term Integration of the Barotropic Equations by the Lax-Wendroff Method," NCAR Ms. No. 58, accepted for publication by the Monthly Weather Review.

Jones, W. L.: "Generation of Small-Scale Oscillations in the Solar Atmosphere," NCAR PM No. 65-27, submitted for publication in the Astrophysical Journal.

Julian, P. R.: "Some Aspects of Tropospheric Circulation during Midwinter Stratospheric Warming Events," Journal of Geophysical Research 70, 757-767, February 1965.

______ and K. Labitzke: "A Study of Atmospheric Energetics during the January-February 1963 Stratospheric Warming," Journal of the Atmospheric Sciences 22, 597-610, November 1965.

Kasahara, A.: "The Dynamical Influence of Orography on the Large-Scale Motion of the Atmosphere," NCAR Ms. No. 64, presented at the International Symposium on Dynamics of Large-Scale Processes in the Atmosphere, June 1965, Moscow, USSR; accepted for publication by the Journal of the Atmospheric Sciences.

______: "On Certain Finite-Difference Methods for Fluid Dynamics," Monthly Weather Review 93, 27-31, 1965.

Knight, C.: "Grain Boundary Migration and Other Processes in the Formation of Ice Sheets on Water," accepted for publication by the Journal of Applied Physics.

______ and N. Knight: "'Negative' Crystals in Ice: A Method for Growth," Science 150, 1819, 1965.

______: The Freezing of Supercooled Liquids, D. Van Nostrand Co., Princeton, New Jersey, in press.

Labitzke, K.: "On the Mutual Relation between Stratosphere and Troposphere during Periods of Stratospheric Warmings in Winter," Journal of Applied Meteorology 4, 91-99, February 1965.

______ and H. van Loon: "A Note on Stratospheric Midwinter Warmings in the Southern Hemisphere," Journal of Applied Meteorology 4, 292-295, April 1965.

Langer, G.: "An Acoustic Particle Counter -- Preliminary Results," Journal of Colloid Science 20, 602-609, August 1965.

______: "Particle Deposition on and Reentrainment from Coniferous Trees, Part II: Experiments with Individual Leaves," Kolloid-Zeitschrift fuer Polymere, Band 204, Heft 1/2, 119-124, 1965.

Latham, J.: "Some Electrical Processes in the Atmosphere," accepted for publication by Weather.

______: "A Mechanism of Charge Transfer in Ice," accepted for publication by Weather.

______: "The Convective Theory of Thunderstorm Electrification," Quarterly Journal of the Royal Meteorological Society 91, 369, 1965.

______: "The Effect of Air Bubbles in Ice on Charge Transfer Produced by Asymmetric Rubbing," Journal of the Atmospheric Sciences 22, 325, 1965.

______ and A. H. Miller: "Potential and Temperature Differences within Hot Pools in Yellowstone Park," Journal of the Meteorological Society of Japan 43, 175, 1965.

______ and ______: "The Role of Ice Specimen Geometry and Impact Velocity in the Reynolds-Brook Theory of Thunderstorm Electrification," Journal of the Atmospheric Sciences 22, 505, 1965.

______ and ______: "Some Electrical Phenomena in Yellowstone Park," in Fifth Yellowstone Field Research Expedition, 31, 103-111, 1965.

______, R. D. Mystrom and J. D. Sartor: "Charge Transfer between Model Ice Crystals Separated in an Electric Field," Nature 206, 1344, 1965.

______ and C. D. Stow: "Electrification Associated with the Evaporation of Ice," Journal of the Atmospheric Sciences 22, 320, 1965.

______ and ______: "The Influence of Impact Velocity and Ice Specimen Geometry on the Charge Transfer Associated with Temperature Gradients in Ice," Quarterly Journal of the Royal Meteorological Society 91, 462, 1965.

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Report of the

ADVANCED STUDY PROGRAM

INTRODUCTION

The NCAR Advanced Study Program (ASP), officially established in the summer of 1964, was created in response to a widely expressed need to draw into the atmospheric sciences additional talented and highly trained people from the mother sciences of mathematics, physics, and chemistry. Specifically, the purpose of the Advanced Study Program is to expose such people to a wide variety of problems in the atmospheric sciences, to provide them with opportunities to pursue some of those problems in depth and, over a period of one or two years, to bring them to the stage of active research contribution. Opportunities for mathematicians, physicists, and chemists to move laterally into the atmospheric sciences have, of course, always existed at NCAR; the Advanced Study Program is simply a more systematic and highly organized effort to make use of a supply of scientific manpower potentially larger than that trained specifically for research careers in meteorology, aeronomy, and related atmospheric sciences.

Philip D. Thompson
Director

PROGRAM

Each year about ten selected people are given one-year visiting appointments to participate full time in ASP. The majority of these are relatively young people who have only recently completed their doctor's degrees, whose acquaintance with the atmospheric sciences may be very recent or very slight, and whose backgrounds in mathematics, physics, and/or chemistry are broad enough that the transition from one field to another can be made without further basic education. Some few, however, are people whose degrees lie five to ten years behind them, whose teaching duties may have limited their ability to carry out original research, and who might profit from intensive exposure to a new and challenging field. With regard to the latter, we are particularly anxious to attract teaching faculty members of undergraduate colleges, whose student bodies are not easily accessible except through direct contact with their own professors.

Through comprehensive and regularly scheduled courses and through shorter, irregular series of seminars, the participants in the ASP 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 courses and seminars 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. Participants are also encouraged to pursue their own research, either in association with members of the ASP staff or with one or more individual programs of the scientific divisions of NCAR. In the normal course of events each participant is expected to seek a position in a university or some other research organization after a year of study and research, except in those instances 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 the ASP would remain as permanent members of NCAR.

STAFF

At the present time, the permanent staff of the ASP are Dr. Philip D. Thompson, Director; Dr. Bernhard Haurwitz; and their assistants Mrs. Ann E. Day and Mrs. Ann Cowley. During 1965 the staff was supplemented by one visiting member, Dr. Ragnar Fjørtoft, Director of the Norwegian Meteorological Institute and Rossby Fellow for 1965. Post-doctoral appointees officially assigned to the ASP were Dr. William Blumen, recently with the University of Oslo; Dr. Jack Powers, Chairman of the Chemistry Department at Ripon College; and Dr. Dieter Ehhalt, University of Heidelberg. In addition, four new appointees who are also actively participating are Dr. D. B. Rao from the University of Chicago; Dr. Ralph Smith from the University of Keele, England; Dr. Reiner Gebhart from the Technische Hochschule, Munich; and Dr. James J. O'Brien from Texas A & M University.

ASP SEMINARS

The first series of lectures under the ASP was given by Dr. Thompson and by Drs. E. R. Benton and W. L. Jones of the LAS staff during the winter and spring of 1965. That series, on statistical hydrodynamics, included discussions of the closure problem, statistical approaches to problems of non-linear instability, the Kolmogoroff-Batchelor theory of homogeneous isotropic turbulence, and Kraichnan's "direct-interaction" hypothesis. This course of lectures and discussions, which was attended by about 25 people from ASP, LAS, and HAO, the Joint Institute of Laboratory Astrophysics (JILA), and the Aerospace Engineering Sciences Department of the University of Colorado, was completed in May 1965.

Later in the spring of 1965 Dr. Fjørtoft gave a six-week series of lectures on integral methods for solving stability problems, and in the fall of 1965 Dr. Haurwitz conducted a working seminar on the theory of internal gravity waves.

Early in 1966 the ASP will institute longer and more comprehensive series of lectures on fields that have undergone rapid and recent development or fields in which several aspects of the same general problem should be brought into closer relationship; e.g., aerosol physics, cloud physics and dynamics, and the role of turbulent exchange processes in the general circulation. The principal purpose of courses of this type will be to delineate the frontiers of existing knowledge and technique and to outline the outstanding problems, rather than to carry out a textbook review of everything that is known in each field. For this reason the ASP will draw heavily on the services of visiting staff and members of the NCAR scientific divisions.

ASP RESEARCH

In addition to participating in seminars, each member of the ASP has been pursuing research in some aspect of the atmospheric sciences. Dr. Haurwitz has extended his earlier work on the theory of internal gravity waves, with particular regard to their apparent connection with the occurrence of noctilucent clouds. This work is described in a recent volume of Advances in Geophysics.

Dr. Blumen has undertaken a theoretical study of the structure of lee waves, the propagation of energy of internal gravity waves, and the statistical effect of mountainous terrain on the large-scale circulation of the atmosphere.

Dr. Ehhalt is actively taking part in the LAS research work in isotope geophysics, directed by Dr. E. A. Martell. Dr. Ehhalt's work was reported at the Symposium on Atmospheric Chemistry held at Visby, Sweden, this past summer. Under a similar arrangement, Dr. Powers participated in the LAS work in photochemistry, headed by Dr. R. D. Cadle, and Powers also assisted with laboratory studies of reaction rates for photochemical processes involving atomic oxygen.

At the request of the Directors of NCAR, an Atmospheric Simulation Colloquium has been organized under the Advanced Study Program to look into the scientific achievements of atmospheric simulation and future possibilities for large-scale research in this area. The study, under George Hidy's (LAS) direction, brings together a number of the NCAR staff and a group of distinguished visitors. During the coming year, many topics of atmospheric simulation will continue to be explored, including certain aspects ranging from the simulation of microphysical processes in clouds to modeling planetary scales of motion. One of the objects of this study is to determine in a systematic way whether or not a national facility or laboratory is feasible, and whether it is needed to carry out a new generation of simulation studies.

ADVANCED STUDY PROGRAM STAFF, 1965

Permanent Staff

Thompson, Philip D. (Director)
Haurwitz, Bernhard

Cowley, Ann
Day, Ann E.

Postdoctoral Appointees

Blumen, William
Ehhalt, Dieter (to September 1965)
Gebhart, Reiner
O'Brien, James J.
Powers, Jack
Rao, D. B.
Smith, Ralph

Long-Term Visitors

Abdullah, Abdul (University of Baghdad, Iraq)
Djuric, Dusan (on sabbatical from University of Belgrade, Yugoslavia)
Fjørtoft, Ragnar (Rossby Fellow from Norweigian Meteorological Institute)
Haug, Odd (assistant to Dr. Fjørtoft, also from Oslo, Norway)
Phillips, Norman (on sabbatical from the Massachusetts Institute of Technology)
Sawada, Ryukichi (Kyusyu University, Hukuoka, Japan)
Yanowitch, Michael (on sabbatical from Adelphi College, New York)

Short-Term Visitors

Bigg, Keith (CSIRO, Australia; from 1 May 1965 to 14 May 1965)
Estoque, Mariano (University of Hawaii; from 23 June 1965 to 26 August 1965)
Fitzgerald, J. W. (University of Chicago; 1 July 1965 to 31 August 1965)
Gilman, Peter (Massachusetts Institute of Technology; from 20 July 1965 to 1 September 1965)
Giorgini, Aldo (Colorado State University; from 1 June 1965 to 15 September 1965)
Hess, Dale (University of Washington; from 15 June 1965 to 31 August 1965)
Hocking, Leslie (University of London; from 14 June 1965 to 31 August 1965)
Isaacson, Eugene (New York University; from 1 August 1965 to 31 August 1965)
Johnson, D. R. (University of Wisconsin; from 7 June 1965 to 25 August 1965)

Lorenz, Edward (Massachusetts Institute of Technology; from 15 June 1965 to 31 August 1965)
Mitchell, Murray (U. S. Weather Bureau; from 1 June 1965 to 31 August 1965)
Morikawa, George (New York University; from 15 June 1965 to 31 July 1965)
Nalley, Samuel (UCAR Fellow; from 3 June 1965 to 31 August 1965)
Parker, Gary (UCAR Fellow; from 19 June 1965 to 31 August 1965)
Pelissier, Joseph (Colorado State University; from 14 June 1965 to 15 September 1965)
Shapiro, Melvin (University of Florida; from 1 June 1965 to 31 July 1965)
Schiller, Barry (University of Florida; from 23 June 1965 to 1 September 1965)
Shuman, Fred (U. S. Weather Bureau; from 10 July 1965 to 24 July 1965)
Thompson, Aylmer (Texas A & M; from 21 June 1965 to 31 August 1965)
Vuorela, Lauri (University of Helsinki; from 3 June 1965 to 21 September 1965)
Williamson, D. L. (Penn State University; from 17 June to 1 September 1965)
Wallace, Michael (Massachusetts Institute of Technology; from 20 July 1965 to 20 September 1965)
Yih, Chia-Shun (University of Michigan; from 20 June 1965 to 10 July 1965)

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Report of the

FACILITIES DIVISION

INTRODUCTION

Since NCAR serves the research needs of the entire community of atmospheric scientists, not merely of its own staff, it receives a considerable number of suggestions for research facilities. Such proposals are carefully analyzed by groups of prominent scientists from outside NCAR, in consultation with the NCAR staff. Certain requirements must be satisfied before NCAR proceeds with plans to establish a facility for joint use with other scientists and institutions: The proposed facility must not exist elsewhere, and yet must be clearly essential to the continued advancement of the atmospheric sciences. Further, it must be so extensive, complex, or specialized that individual universities have found it impractical to establish similar facilities for their own use.

During the year 1965, NCAR 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 Division in July 1964.

To meet specific needs of its own research programs, NCAR also continued to operate four support groups: the NCAR Library, organized in 1961; the Machine Shop, established in 1962; the Field Observing Support Facility, established in 1963 and the Electronics Shop, established in 1964.

Each of these facility groups shares three principal functional responsibilities: (1) to provide engineering and technical support services as required by NCAR and the university atmospheric sciences community, (2) to conduct developmental research aimed at improved sensing, collecting and processing of atmospheric field data, and (3) to provide a national focal point for the exchange of technical information of interest to research scientists. A comprehensive resume of the past year's operations is presented in the following sections of this report.

Study and planning activities included: (1) a continuation of the cooperative analysis of requirements for an atmospheric simulation facility (the results of this study are expected to be reported in September or October of 1966), (2) further investigation of the research data handling problem, and (3) a consideration of the desirability of broadening the responsibilities of the Field Observing Support Facility to include university requirements outside NCAR. In response to a request of the Board of Trustees, the UCAR Council of Members considered this question and in December 1965 recommended the establishment of the NCAR Field Observing Support Facility as a joint-use activity.

Daniel F. Rex
Director of Facilities

SCIENTIFIC BALLOON FACILITY

In 1965 the NCAR Scientific Balloon Facility conducted flight operations from its primary launch station at Palestine, Texas, and its secondary site at Page, Arizona. Flights were also made from the U. S. Naval Air Facility, Litchfield Park, Arizona. The Balloon Facility provided balloon flight support for the Equatorial Balloon Expedition (EQEX) in Hyderabad, India.

LAUNCH FACILITIES

On 1 November 1965, contract operations at Palestine were transferred from Raven Industries to Winzen Research, Inc., of Minneapolis, Minnesota. The Winzen group, consisting of 15 people, will conduct launching, tracking, and payload recovery of scientific balloon flights. NCAR has assumed a more direct responsibility for flight-station operations at Palestine and will strengthen its engineering and technical staff accordingly. With NCAR providing essential skills and supervision, better continuity of operation will be provided when contract operations are transferred, as they were in November.

Four new offices and a briefing room were added to the operations building at Palestine. A prefabricated steel building was erected for checkout of the Coronascope II telescope. Plans for the inflation shelter (Clamshelter) have been completed, and requests for proposals are being prepared. Separate bids will be requested for the structure, its moving system, and necessary site development.

An agreement between the National Science Foundation and the Bureau of Reclamation has provided a site at the Glen Canyon Airport at Page, Arizona, for an operations building and a paved launch area. Plans and bid specifications for the building and launch area are complete, but construction has been postponed until FY-68 when additional funds should become available for this purpose.

A temporary launch facility has been established at Christchurch, New Zealand, to be used for a full-scale field test of the GHOST

(Global HOrizontal Sounding Technique) program. This launch facility is fully equipped and ready for test operations, which are expected to commence in early 1966.

BALLOON DESIGN AND TESTING

In 1964 a serious problem was encountered with the unexpected burst of balloons at altitudes of 30,000 to 60,000 ft; 18% of all balloons launched at Palestine were lost because of this problem. In 1965 this loss was reduced to 7%. Although this reduction was primarily due to improved balloon materials, significant progress was made in understanding the ascent failure problem. With continuing improvement in materials and use of newly designed top-reinforced balloons, ascent burst should soon be reduced to a minor problem.

The Scientific Balloon Facility is developing materials testing methods especially designed to produce test results which correlate significantly with balloon-performance characteristics. The classic test for balloon materials is a one-axis test, designed for testing film for packaging purposes, which does not give much information relevant to balloon performance. The new methods use three testing devices: a biaxial tester, a dropping-weight tester, and a low modulus strain gage. These will provide realistic data on film strength, cold brittleness, and toughness.

ELECTRONIC SUPPORT SYSTEM

A lightweight telemetry and command system was completed and tested in 1965. This system is being packaged in modular form so that only the necessary components must be used for an individual flight, permitting a great reduction in the weight of the electronics equipment used for many flights.

GHOST BALLOON PROGRAM

The GHOST balloon program is a joint ESSA-NCAR project for the development of an atmospheric data-gathering system using superpressure balloons capable of floating at a constant-density level for many months. NCAR's participation in the development of a global weather-observing system is limited to establishing the feasibility of an operational system.

A lightweight solar-powered electronic system has been developed which has its mass dispersed through a large volume, transmits a signal which can be received up to 5000 miles from the transmitter, and provides four information channels for data. One of these channels is used to locate the balloon by measuring the local sun angle. The other three channels will be available to transmit information about atmospheric conditions.

Superpressure balloons have been developed in several sizes. Each size is designed to carry sensors and an electronics package to a specified density altitude and to remain at that altitude for an extended period.

Operational tests of the system will be conducted in the southern hemisphere. Balloons will be launched in New Zealand by an NCAR party under the supervision of Vincent E. Lally, and the transmissions will be monitored by stations in South America, South Africa, Australia, New Zealand, Mauritius Island, American Samoa, and Tahiti, and by a ship cruising in Antarctic waters. Flights are scheduled to begin as a joint New Zealand-U. S. program in early 1966.

CORONASCOPE II

Two successful flights were made from Palestine in 1965 in support of Newkirk's Coronascope II program. These flights were made on 3 June and 1 July. Future flights in support of Coronascope II can be made on a routine basis without requiring additional equipment or special preparations.

POLARISCOPE AND MARINER

The Balloon Facility provided support for the Polariscope and Mariner projects of the University of Arizona. The first Mariner flight was launched on 11 May at Palestine, and the first Polariscope flight is scheduled to be launched from the U. S. Naval Air Facility at Litchfield Park, Arizona, early in 1966.

EQUATORIAL BALLOON EXPEDITION (EQEX)

In May 1964 NCAR was requested by the National Science Foundation to conduct balloon flights for a joint U. S.-Indian cosmic-ray research expedition to the vicinity of the equator. This support was provided by a contract crew from Raven Industries under the direction of an NCAR program manager, Robert S. Kubara. Seventeen flights were made at Osmania University in Hyderabad, Indian, during March and early April 1965. Of the 17 flights, three balloons failed on the ground and one burst during ascent. All scientific packages scheduled for flight were flown. This expedition is considered a major success, especially since the flight program faced many operational and logistical problems as a consequence of the remote location of the operational site.

NEWSLETTER AND TEST REPORTS

Publication of the quarterly newsletter Scientific Ballooning continued during 1965.

Three reports prepared in connection with the Scientific Balloon Facility's materials research project were published during 1965. These reports were: NCAR Facilities Report FRB-4, Strength Characteristics of DuPont "Surlyn A" Film; NCAR Technical Note TN-5, Material Strength Properties of Visqueen X-124 Film; and NCAR Technical Note TN-9, Material Strength Properties of Startex SL 1883 Film.

COMPUTING FACILITY

The NCAR Computing Facility evolved from the LAS computing group and was transferred to the Facilities Division as a joint-use facility on 1 July 1964. However, the major support furnished by the Computing Facility has continued to be for NCAR's own research. Most of the requests for computer support from organizations other than NCAR have been from universities which are located nearby or from universities with faculty members who have been associated with NCAR. In order to inform other institutions about the services available from the NCAR Computing Facility, Roy Jenne plans to visit ten or twelve schools to explain the function of the Facility, outline its services, and answer questions. This is being done in response to a recommendation of the Computing Facility Advisory Panel, which expressed concern over the small amount of computer time being utilized by outside users. It is known, however, that several potential users have been waiting for the Control Data 6600 which will replace NCAR's Control Data 3600 in January 1966. This new computer will be three to five times as fast as the 3600 in routine operations, and for special problems, with extra programming effort, the 6600 can be ten times as fast as the 3600.

COMPUTER OPERATIONS

During 1965 there was a gradual but steady increase in the use of the Computing Facility both by outside users and by NCAR researchers. Additions to the Computing Facility staff in 1965 included three computer operators and four mathematical programmers. The computer was operated on three shifts all year, and since May the computer has operated seven days a week and twenty-four hours a day. Down-time has generally been less than five hours per month.

THE dd80

In August a dd80 was added to the major equipment. This is a device which combines a cathode-ray tube and a high-speed camera. Computer-originated images are projected onto the tube in a sequence which is recorded on film, to produce "hard copy" output of graphs, plots and charts. Some very successful movies have also been made with this process.

THE CONTROL DATA 6600

The Computing Facility originally planned to install the new Control Data 6600 on 1 July 1965. As a result of manufacturing delays and difficulties with available software for the 6600, NCAR and the Control Data Corporation agreed that a series of pre-acceptance tests would be run by NCAR personnel on the 6600 at the Control Data plant in Chippewa Falls, Wisconsin. It was also agreed that Control Data would install the 3600 at a temporary location in the Boulder area, at their expense, for NCAR's use while the 6600 undergoes acceptance tests at NCAR. Successful pre-acceptance was completed in December, and the 6600 will be delivered to NCAR in early January 1966.

Floor layouts for the 6600 in the Computing Facility area in the PSR-2 building on 30th Street are complete. All electrical, plumbing, and lighting problems seem to have been solved. A temporary location has been prepared for the 3600 in Littleton, Colorado.

FUTURE COMPUTER REQUIREMENTS

A study is being conducted to determine speed and size requirements for a "super computer" to be acquired sometime in the future for work with numerical models of the general circulation of the atmosphere and of atmospheric convective processes. NCAR representatives have met for discussions with an IBM group which is considering computer requirements in the atmospheric sciences. They have also met with Professor Daniel Slotnick of the University of Illinois, who is designing a high-speed, large-capacity parallel computer to be built within the next two or three years. Lewis, Gary, Kasahara, Lilly, Rotar, Thompson, and Washington are among those at NCAR who have participated in this study of future computer requirements.

RESEARCH AVIATION FACILITY

The NCAR Research Aviation Facility completed its first full year of operations in 1965. Flight operations included 329 flights, totalling 989 hours, in support of 13 research projects. General support services provided by the Facility included information exchange and student training.

AIRCRAFT

The Aviation Facility's first aircraft, a twin-engine supercharged Beech Queen Air 80, has been in use since 1964. A rapid increase in flight-support requirements led to the leasing of a second Queen Air 80 in May 1965. In October the Aviation Facility Advisory Panel recommended that the Facility procure a light twin-engine jet aircraft. Such an aircraft would enable the Facility to support certain projects whose altitude requirements exceed the Facility's present capability and to provide better support than is now possible for a large number of projects. A study of light executive-type jet aircraft was undertaken, and four aircraft were evaluated in terms of NCAR's requirements. This study concluded that the North American Sabreliner was the most appropriate aircraft and recommended that the Aviation Facility acquire a Sabreliner.

OPERATIONS BASE

NCAR has obtained an option to lease a five-acre site at the Jefferson County Airport to be used as a permanent operations base. In November 1965, to provide temporary accommodations, NCAR leased 5000 sq ft. of hangar space and 1500 sq ft of office, laboratory, maintenance, and storage space from Roach Aircraft, Inc. This space will be used to conduct routine maintenance, and will include an instrumentation check out and calibration laboratory.

INSTRUMENTATION

New sensors which have been developed and installed in the aircraft for test and evaluation include a frost-point hygrometer, a rotating-bowl thermometer, a pressure transducer, a time standard and counter system, and a platinum element reverse-flow thermometer. New sensors for measuring liquid water content and detecting precipitation particles are in the preliminary design stage. The NCAR Aircraft Research Instrumentation System (ARIS), a hybrid (analog and digital) magnetic tape recording system, has been developed and is undergoing testing and evaluation. This system will record 36 channels of data for periods up to 8 hr.

INFORMATION EXCHANGE

The *Scientific Aviation Newsletter* was published quarterly during 1965. In response to a request made in 1964 by the Interdepartmental Committee on Atmospheric Sciences, a catalog of atmospheric research aircraft and instrumentation currently in use or planned for the near future, *Aircraft and Instrumentation in Atmospheric Research* (NCAR Technical Note TN-6), was published in September 1965.

STUDENT TRAINING

Two graduate students joined the Aviation Facility from June to September to become familiar with the use of aircraft and related instrumentation for atmospheric research. This is the beginning of a university graduate student summer training program which should be expanded in the future.

FUTURE PLANS

In addition to the procurement of a light twin-engine jet aircraft and the expansion of the summer training program, plans for 1966 include procurement of a second complete ARIS system and sponsorship of an atmospheric research aircraft fly-in and instrumentation symposium.

FIELD OBSERVING SUPPORT FACILITY

The Field Observing Support Facility (FOSF) was established in 1964 to provide support services and equipment for field programs of LAS and of the Facilities Division. An increasing number of requests for services and equipment were received during 1965 from universities and other institutions outside NCAR. Thus it seemed desirable to broaden the mission of FOSF by designating it a joint-use facility to provide support for the entire atmospheric sciences community. A recommendation to this effect was made to the UCAR Board of Trustees in October 1965. The Board asked the Council of Members to study the request and to recommend a course of action. In December the Council of Members endorsed the recommendation, and affirmation by the UCAR Board is expected in January 1966.

MARSHALL FIELD SITE

The Marshall Field Site is being used almost daily for radar observations and for field equipment maintenance. Future plans for the site include development of the following facilities: a weather station, an atmospheric electricity station, an ozone sounding station, a radar test site, an antenna range, a warehouse facility for radar spare parts, and a receiving station for monitoring GHOST balloons and satellites.

RADAR

The M-33 radars have been extensively modified. Modifications include a combination radiosonde receiver and tracking radar; a calibrated, range-gated video integrator for snow and precipitation studies; extended plotting-board range; improved receiver characteristics; field-data processing and recording; video amplifier improvements for the iso-echo recording of reflectivity values; automatic radar tracking of transponders on constant density-altitude superpressure balloons; and utilization of a precision parabolic antenna on 10 cm and a pseudo-CAPPI system on 3 cm.

HIGH LEVEL PROFILE EQUIPMENT

A system which provides temperature and humidity data from balloon-borne sensors and simultaneous tracking of the radiosonde package by radar was provided by installing a radiosonde receptor in an M-33 radar van.

BOUNDARY LAYER PROFILE SYSTEM

A system is needed to make inexpensive measurements of profiles and fluctuations of winds, temperature, moisture, and radiation in the layers below 5000 ft. Initial development work used a balloon in the shape of an airfoil to carry the sensors aloft. Tests were also made with fabric kite wings which had an altitude capability of about 2000 ft with payloads up to 25 lbs.

OPERATIONS

The Field Observing Support Facility has continued to provide radar support for the balloon station at Palestine, Texas. Radar support, using a modified T-33 system installed on Mt. Harris, was also continued for Rex's Steamboat Springs precipitation rate study. An M-33 tracking radar was provided for a joint study of warm rainfall mechanisms conducted at Hilo, Hawaii, by the University of Nagoya (Japan), the University of Hawaii, the Illinois State Water Survey, Cornell Aeronautical Labs, and NCAR. The Facility is supporting Lilly's mountain-wave study by providing a network of recording anemometers and radar tracking for constant-altitude balloons which will be released on the western side of the Continental Divide and tracked as they are carried eastward. Management of the ozonesonde program which was formerly conducted by LAS has been assumed by FOSF. The Facility is conducting a surface-wind study at Palestine, Texas, for the purpose of exploring the feasibility of short-period wind-forecast techniques.

WINDSOR FIELD SITE

The transfer of an abandoned Air Force missile site near Windsor, Colorado, to the NSF for use by NCAR has been approved. This site will be useful in thunderstorm and hail research in northeastern Colorado and in snowfall studies over the eastern slope of the Rockies. Colorado State University has expressed an interest in periodic use of the site.

MOHOLE

The National Science Foundation has endorsed the use of Project MOHOLE drilling platform for atmospheric research observations and has designated NCAR as the coordinator for such programs. NCAR, through Dr. Harold W. Baynton, will be responsible to NSF for determining priorities and scheduling so that the greatest number of worthwhile programs may be included.

LIBRARY

AUTOMATED INFORMATION RESEARCH

The Automated Information Research (AIR) program, which was begun by the NCAR Library in 1964, was developed and integrated into routine operations during 1965. The Library is now working with a semi-automated system based on data storage in the form of key-punched tabulating cards. The cards are manipulated by hand or with appropriate data-processing equipment. This semi-automated system is gradually being substituted for conventional manual routines in acquisition, announcing, indexing, and circulating operations.

The next step will be to develop an automated system which will use a computer for storage and manipulation of library records. The semi-automated system, which already has the necessary data in machine-readable punched-card form, will furnish the input for the computer-based automated system. The primary task in establishing the automated system will be to develop the necessary computer programs. The pilot project for the automated system is an adaptation of a computerized system for ordering, check-in, routing, and binding of journals developed by the University of California at La Jolla.

An ultimate system which is now being studied will be known as the Cybernated NCAR Library System. This system will attempt to use the computer for certain library decision-making processes, and may involve interaction with other libraries which utilize computer systems.

AREA UNION LIST OF JOURNALS

Production of an area union list of journals, to cover all major science and engineering journal holdings in libraries from the University of Wyoming at Laramie to the Air Force Academy near Colorado Springs, was undertaken by the NCAR Library in 1964. This project has continued, and an interim edition of the union list, covering 12 libraries, has been printed. A final edition should be compiled early in 1966, and will be edited by a group from the local chapter of the Special Libraries

Association. This publication should be useful to technical librarians throughout the area.

INTEGRATED BIBLIOGRAPHY PILOT STUDY

This project was undertaken by the University of Colorado in cooperation with the NCAR Library. Although the subject matter of this bibliography study was not connected with the atmospheric sciences, the computer programs which were developed for the study, along with the experience which was gained by participating in the study, should be extremely valuable in developing the proposed cybernated system for the NCAR Library.

TRANSLATION

The NCAR Library has established a translating center to continue the translation of foreign articles, books, and reports which was formerly done by the library on an informal basis. The number of translations produced in 1965 was more than double that for 1964. It has been proposed that an informal clearing house be established among organizations which produce translations of material in the atmospheric sciences. This would insure that important material is translated and should prevent wasted effort spent in translating material which is already available in English translation.

HOLDINGS AND ACCESSIONS

During 1965 the NCAR Library holdings increased from 11,000 to 16,500 volumes. This is more than half of the total collection of 30,000 volumes which has been projected as the minimum figure that should be reached by the end of 1968. Some of the older holdings have been stored in warehouse areas. This bulk storage will be necessary until the library moves into its new quarters in NCAR's permanent building, where adequate space will be available for shelf storage of all holdings.

MACHINE SHOP

During 1965, 254 work orders were completed by the machine shop. About 50% of these jobs were formally designed projects which originated with the engineering design group. There was a marked increase in projects involving the design and fabrication of precision instruments. Both personnel and equipment were added to the machine shop in 1965, and it was necessary to rearrange machines, work space, and material stocks to accommodate this increase. Future expansion of the shop facilities will be limited by a lack of floor space at the 30th Street location, but the move to the new building should alleviate this situation. One designer and three machinists joined the shop staff during 1965, increasing the total staff to 17 people. Around the middle of the year, a machine shop foreman was selected from the shop crew. This produced a noticeable increase in the efficiency of machine shop operations. Twelve new major items of machine tool equipment were installed during the year, and two government excess-property machines were acquired, reconditioned, and put into service.

In order to keep abreast of NCAR's increasing research activities, it will be necessary for the machine shop to continue to provide increased skills, equipment, and materials. It will also be necessary to improve administrative procedures to keep pace with this increase in shop activities, especially in areas such as coordination between the scientific groups and the design group and shop regarding cost estimates and final cost figures.

ELECTRONICS SHOP

The Electronics Shop has continued to increase its service, although its basic functions have not been changed.

The electronics stockroom has increased its stock by 100% during 1965. One clerk has been added to the staff.

OTHER RESEARCH SUPPORT ACTIVITIES

ATMOSPHERIC SIMULATION FACILITY STUDY

A study directed toward determining NCAR's possible role in the development of a new atmospheric simulation facility or in more efficient utilization of existing facilities has continued throughout 1965. This study is being conducted by George Hidy under the Advanced Study Program, and is discussed in the ASP section of this report.

DATA-CONVERSION FACILITY

Study of the feasibility and potential usefulness of a large-capacity generalized data-conversion facility has continued. A pilot study of data conversion operations is being conducted using the ground read-out portion of the Aviation Facility's ARIS system. During 1966, data-handling problems connected with research being performed by Lilly and Newton will be used as test cases. It is hoped that this pilot study will produce a design for a practical data-conversion system.

GLASS BLOWING FACILITY

On the advice of the Facilities Advisory Panel, a scientific glass blower was hired in December, and a start has been made toward establishing a glass blowing shop. This shop should be in full operation by March 1966.

FACILITIES DIVISION STAFF, 1965

Director's Office

Management:

Rex, Daniel F. (Director, Facilities Division)

Professional:

Morris, Alvin L. (to May)
Palmer, Charles A., Jr.

Support:

Hunt, Jay (from July)
Miller, Natalie R.
Pittman, Earle S.
Stitt, Jane S. (to July)

NCAR Scientific Balloon Facility

Management:

Lally, Vincent E. (Superintendent)
McCreary, Frank E., Jr. (Superintendent)
Morris, Alvin L. (from May) (Manager)

Professional:

Angevine, Jack M.
Baker, Harold L. (from January)
Bilhorn, Thomas W.
Frykman, Robert W.
Kubara, Robert S.
Lichfield, Ernest W.
Mellor, George P.
Rickel, A. Brewster (from April)
Shipley, Alfred
Snyder, Ronald L.
Solot, Samuel B.
Sparkman, John W., Jr.
Verstraete, Marcel L.
Warren, John C.

Support:

Bishop, Edward E.
Carlson, Neil
Hankins, Clinton (from November)
Holdsworth, Elizabeth P.
Luly, Marion (from May)
Lumpkin, Tom R. (from November)
Paschall, William C. (from July)
Starry, James L.
Wright, Lettie M.

Computing Facility

Management:

Lewis, Glenn E. (Head)

Professional:

Adams, Jeanne C.
Biro, Robert P.
Drake, Margaret A.
Ellis, Chester W.
Gary, John M.
Hargreaves, Sylvia
Jenne, Roy L. (from January)
Kay, Alan C.
Kitts, David L.
Korts, Richard (to September)
Meeker, Gary O.
Miller, Jack H.
O'Lear, Bernard T.
Oliger, Joseph E. (from September)
Roach, Gerard (from August)
Robertson, David
Rotar, Paul A.
Swarztrauber, Paul N.
Takamine, Joyce A. (from March)
Wagner, Loren (to April)
Walker, W. Hugh
Williams, Larry D.
Williston, Donald G. (from June)
Working, Robert D.

Support:

Austin, Donald M.
Bloom, Betty L. (from March)
Beardsley, Carol L. (from April)

Frank, Richard J. (from April)
Franks, Wendell A.
Germann, Edward A.
Hedgecock, Suzanne (to March)
Klepacs, Benjamin
Lukasik, Walter A. (from March)
Nesmith, Dorritt E.
Patrick, Richard L. (from August)
Pieper, Bonnie (from November)
Short, Georgianna (from June)
Sprague, Georgia L. (from February)
Walden, Fred P. (from June)

NCAR Research Aviation Facility

Management:

Hinkelman, John W., Jr. (Manager)

Professional:

Beabout, Robert G. (from July)
Brown, Edward N.
Bullock, J. William
Dascher, Albury J.
Finke, Denford (from March)
Hines, William F. (from March)
Nagle, Frederick N. (to February)
Prantner, Gene D. (from September)

Support:

Busch, Melvin E. (from September)
Denton, Ferne (to March)
Hieke, Ursula (from March)
Hudson, Clyde (from September)

Field Observing Support Facility

Management:

Lanterman, William S., Jr. (Manager)

Professional:

Baynton, Harold W.
Eklund, Donald A.
Saum, George H., Jr.
Tefft, Jack D.

Support:

Amen, Charles E. (from October)
Bragg, William W. (from June)
Crooimans, Peter (from November)
Eis, Roy B.
Gafvert, Betty L.
Janssen, Jerry M. (from September)
Lewis, Brian W.
Marshall, Robert C. (from November)
McKay, Dale B. (from November)
Sorenson, Alan L.
Von Krogh, Joan E. (from November)

Library

Management:

McCormick, Jack M. (Chief Librarian)

Professional:

Groodin, Ivan S.

Support:

Allen, Barbara (from September)
Barrett, Barbara Ann (from July)
Crosby, William (from November)
Daldos, Linda J. (from April)
Dean, Dorothy E.
Davis, Linda G. (from November)
Kirkpatrick, Maurine A. (from August)
Leyner, Carol
Long, William
McDonald, Terry
Minkel, Dorothy C.
Morris, Gaylene (from September)
Sanford, Josephine P.
Sheffield, Shelby J. (from March)
Sisk, Laury J.

Machine Shop

Management:

Hewett, Marvin C. (Manager)

Professional:

Johnson, H. Paul

Support:

Abram, Edmund
Baptist, Page A.
Crowther, Jack W.
Dombrowski, William (from June)
Evans, Owen D., Jr. (from March)
Erickson, Richard A. (from September)
Geisert, Henry P.
Howard, Michl B.
Knoblock, H. Fred
Lambdin, Edward D.
Lewis, Richard D., Sr.
Mathews, Hayden F.
Novac, Ben L. (from March)
White, Russell D.
Zimmer, Frederick J.

FACILITIES DIVISION PUBLICATIONS, 1965

Bilhorn, T. W.: "Scientific Ballooning at NCAR," Bulletin of the American Meteorological Society 46, 543-545, September.

______: "Balloons for Scientific Research," Astronautics and Aeronautics, 42-46, December 1965.

______: "NCAR Balloon Flight Statistics," to be published in Proceedings of the AFCRL 1965 Scientific Balloon Symposium, Portsmouth, New Hampshire.

Gary, J.: "Hyman's Method Applied to the General Eigenvalue Problem," Mathematics of Computation 19, No. 90, 314-316, April 1965.

______: "Computing Eigenvalues of Ordinary Differential Equations by Finite Differences," Mathematics of Computation 19, No. 91, 365-379, July 1965.

______: "A Computer Survey of Linear Atmospheric Instability," NCAR PM No. 64-13, February 1965.

Jenne, R. L.: "A World Data System for Computer Input," NCAR MS No. 130, Preliminary Report, 1965.

Lewis, G. E.: "Analytic Continuation Using Numerical Methods," Methods in Computational Physics, Vol. 4, New York, Academic Press, 1965.

Saum, G. H., Jr. and W. H. Fischer: "Measurements of Noise Emission from Mercury Balls," Nature 205, 558-561, February 6, 1965.

Strength Characteristics of Du Pont "Surlyn A" Film, FRB-4, 1965.

Material Strength Properties of Visqueen X-124 Film, NCAR Technical Note, TN-5, 1965.

Aircraft and Instrumentation in Atmospheric Research, NCAR Technical Note TN-6, 1965

Material Strength Properties of Startex SL 1883 Film, NCAR Technical Note, TN-9, 1965.

Report of the

ADMINISTRATIVE AND SUPPORT SERVICES DIVISION

INTRODUCTION

During 1965, as in previous years, the Administrative and Support Services Division continued to serve the growing needs of the research and facilities programs.

The staff of the Division includes specialists in administrative fields such as finance and purchasing, contracts, personnel, plant construction and maintenance, and operation of services such as the motor pool and the mail room. Direct support services provided by the Division to the NCAR research activities include scientific editing, writing, and publications production; organization of meetings and conferences; design and layout of exhibits and publications; technical illustration; photography and photo lab services; and printing and reproduction. The Division also includes the staff of the Director of NCAR.

NCAR'S PERMANENT LABORATORY

At the end of 1965 the Division was deeply involved in detailed planning for the move to NCAR's permanent laboratory building at the mesa site. This planning includes assignment of office and laboratory space, layout of laboratories, layout of service areas such as the cafeteria and the parking lot, and logistic planning for the physical move of staff and equipment to the new building.

The first increment of construction, consisting of the central core structure and two towers, was 75% complete at the end of 1965 and should be substantially complete by the summer of 1966. This first increment will include 190,000 gross sq ft of space. Construction of another five-story tower and a two-story addition for the High Altitude Observatory, planned for 1968, will add another 100,000 gross sq ft. This second increment of construction will allow the High Altitude Observatory staff to move to the permanent building, will accommodate an increased number of visiting scientists, and will permit relocation of laboratories which will be housed temporarily in the basement of the first increment, in space intended eventually for storage areas.

CONFERENCES AND VISITING SCIENTISTS

CONFERENCES HELD AT NCAR

Calendar Year 1965

CONFERENCE ON ATMOSPHERIC LIMITATIONS TO OPTICAL PROPAGATION

17 - 19 March, Boulder, Colorado.
Co-hosted by NCAR and the National Bureau of Standards.
250 participants.

Proceedings of the Conference on Atmospheric Limitations to Optical Propagation, published by the Central Radio Propagation Laboratory of the National Bureau of Standards.

SEMINAR ON THE CAUSE AND STRUCTURE OF IONOSPHERIC SPORADIC E

9 - 11 June, Estes Park, Colorado.
Co-hosted by NCAR and the National Bureau of Standards.
40 participants.

WORKSHOP ON THE EXTRA-TERRESTRIAL INFLUENCES ON THE GENERAL CIRCULATION

16 June - 28 July, Boulder, Colorado.
Co-sponsored by NCAR and the Office of Naval Research.
Hosted by NCAR.
34 participants.

Proceedings of the Seminar on Possible Responses of Weather Phenomena to Variable Extra-Terrestrial Influences, published as NCAR Technical Note TN-8.

SYMPOSIUM ON THE SOCIAL AND ECONOMIC ASPECTS OF WEATHER MODIFICATION

1 - 3 July, Boulder, Colorado.
Sponsored by the National Science Foundation.
Hosted by NCAR.
57 participants.

OPEN MEETING ON THE EXTRA-TERRESTRIAL INFLUENCES ON THE GENERAL CIRCULATION

29 - 30 July, Boulder, Colorado.
Hosted by NCAR.
100 participants.

(A continuation of the Workshop on the same subject.)

WORKSHOP ON THE USE OF SATELLITE DATA IN METEOROLOGICAL RESEARCH

25 - 31 August, Boulder, Colorado.
Sponsored and hosted by NCAR.
100 participants.

Proceedings of the Workshop on the Use of Satellite Data in Meteorological Research, to be published as NCAR Technical Note TN-11.

SYMPOSIUM ON THE CAUSES OF CLIMATIC CHANGE

31 August - 1 September, Boulder, Colorado.
Sponsored by NCAR.
Co-hosted by NCAR, University of Colorado, and INQUA.
30 participants.

MEETING OF THE SOLAR PHYSICS SUB-COMMITTEE OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

15 - 17 September, Boulder, Colorado.
Hosted by NCAR.
30 participants.

FIRST NATIONAL SYMPOSIUM ON HAIL SUPPRESSION

14 - 15 October, Dillon, Colorado.
Sponsored by the National Science Foundation.
Hosted by NCAR.
27 participants.

Report of the First National Symposium on Hail Suppression, printed by NCAR.

VISITING SCIENTISTS

Name	Affiliation
Abdullah, A. J.	University of Baghdad, Baghdad, Iraq
Asai, Tomio	Meteorological Research Institute, Tokyo, Japan
Baer, Ferdinand	Colorado State University, Fort Collins, Colorado
Bates, Fred C.	St. Louis University, St. Louis, Missouri
Bigg, Keith	Commonwealth Scientific and Industrial Research Organization, Sydney, Australia
Blumen, William	University of Oslo, Blindern, Norway
Bunting, J. Graham	Hartley Victoria College, Manchester, England
Brier, Glenn W.	U. S. Weather Bureau, Washington, D. C.
Ciner, Evan	Universidad Nacional de Cuyo, San Juan, Argentina
Clarke, R. H.	Commonwealth Scientific and Industrial Research Organization, Victoria, Australia
Cole, Keith D.	University of Chicago, Chicago, Illinois
Culberson, Helen R.	University of Colorado, Boulder, Colorado
Dingle, A. Nelson	University of Michigan, Ann Arbor, Michigan
Djordjevich, Nenad	University of Belgrade, Belgrade, Yugoslavia
Djuric, Dusan	University of Belgrade, Belgrade, Yugoslavia
Dodge, James C.	University of Colorado, Boulder, Colorado
Downen, Douglas W.	St. Louis University, St. Louis, Missouri
Dütsch, Hans U.	Federal Technical University, Zurich, Switzerland
Ehhalt, Dieter	University of Heidelberg, Heidelberg, Germany
Eichenberger, E.	Federal Institute of Technology, Zurich, Switzerland
Eloranta, Edwin	University of Wisconsin, Madison, Wisconsin
Estoque, Mariano	University of Hawaii, Honolulu, Hawaii
Evans, Howard	Colorado State University, Fort Collins, Colorado
Fitzgerald, James W.	University of Chicago, Chicago, Illinois
Fjørtoft, Ragnar	Det Norske Meteorologiske Institutt, Blindern, Norway

Fraser, Robert S.	TRW Space Technology Laboratories, Redondo Beach, California
Friesen, Richard B.	University of Colorado, Boulder, Colorado
Fritts, Harold	University of Arizona, Tucson, Arizona
George, John	University of Colorado, Boulder, Colorado
Gilman, Peter	The Massachusetts Institute of Technology, Cambridge, Massachusetts
Giorgini, Aldo	Colorado State University, Fort Collins, Colorado
Haug, Odd	Oslo, Norway
Hearn, Anthony G.	United Kingdon Atomic Energy Authority, Culham Laboratories, Albingdon, Berkshire, England
Hess, Dale	University of Washington, Seattle, Washington
Hiei, Eijiro	Tokyo Astronomical Observatory, Mitaka, Japan
Hocking, Leslie	University College, London, England
Isaacson, Eugene	Courant Institute of Mathematical Sciences, New York University, New York
Johnson, Donald R.	University of Wisconsin, Madison, Wisconsin
Kato, Shoji	Institute of Space Studies, Goddard Space Flight Center, Greenbelt, Maryland
Kendall, Peter C.	Sheffield University, Sheffield, England
Kochanski, Adam	U. S. Weather Bureau, Washington, D. C.
Kutzbach, John E.	University of Wisconsin, Madison, Wisconsin
Latham, John	Manchester College of Science and Technology, Manchester, England
Liggett, William	Stanford University, Menlo Park, California
London, Julius	University of Colorado, Boulder, Colorado
Lorenz, Edward N.	The Massachusetts Institute of Technology, Cambridge, Massachusetts
Lowery, Michael	Beloit College, Beloit, Wisconsin
Maeda, Hiroshi	Kyoto University, Kyoto, Japan
Mateer, Carlton L.	Meteorology Branch, Department of Transport, Toronto, Canada
Mehollin, Elaine	Beloit College, Beloit, Wisconsin
Mesinger, Fedor	University of Belgrade, Belgrade, Yugoslavia
Mitchell, J. M., Jr.	U. S. Weather Bureau, Washington, D. C.

Morikawa, George	Courant Institute of Mathematical Sciences, New York University, New York
Musman, Stephen	Princeton University Observatory, Princeton, New Jersey
Nalley, Samuel	Arkansas State Teachers College, Conway, Arkansas
Nordö, Jack	U. S. Weather Bureau, Washington, D. C.
Noxon, John F.	Harvard University, Cambridge, Massachusetts
Okita, Toshiichi	Japanese Institute of Public Health, Tokyo, Japan
Pallmann, Albert J.	St. Louis University, St. Louis, Missouri
Parker, Gary	Dartmouth College, Hanover, New Hampshire
Pelissier, Joseph M.	Colorado State University, Fort Collins, Colorado
Phillips, Norman A.	The Massachusetts Institute of Technology, Cambridge, Massachusetts
Powers, Jack W.	Ripon College, Ripon, Wisconsin
Preining, Othmar	First Institute of Physics, University of Vienna, Vienna, Austria
Rao, D. B.	University of Chicago, Chicago, Illinois
Reddy, C. Abhirama	Ionospheric Research Laboratory, Andhra University, Waltair, India
Robin, James E., Jr.	University of Colorado, Boulder, Colorado
Rooth, Claes	Woods Hole Oceanographic Institute, Woods Hole, Massachusetts
Rossby, Stig	University of Wisconsin, Madison, Wisconsin
Roxburgh, Ian	Queen's College, University of London, London, England
Rudge, Michael	The Queen's University of Belfast, Belfast, North Ireland
Saito, Takao	Geophysical Institute, Tohoku University, Sendai, Japan
Sawada, Ryukichi	Kyusyu University, Hukuoka, Japan
Schiller, Barry	University of Florida, Tallahassee, Florida
Schmidt, Hermann U.	Max-Planck Institute für Physik und Astrophysik, Munich, Germany
Schreck, Roger	Kansas State Teachers College, Emporia, Kansas
Sekera, Zdenek	University of California, Los Angeles, California

Shapiro, Melvin A.	University of Florida, Tallahassee, Florida
Shuman, Fred	U. S. Weather Bureau, Washington, D. C.
Söderberg, Bengt	Royal Swedish Air Force, Barkarby, Sweden
Strittmatter, Peter	Queen's College, University of London, London England
Telford, James W.	Commonwealth Scientific and Industrial Research Organization, Sydney, Australia
Thompson, Aylmer H.	Texas A & M University, College Station, Texas
Thompson, Dennis	University of Wisconsin, Madison, Wisconsin
Twitchell, Paul F.	Office of Naval Research, Boston, Massachusetts
Uchida, Yutaka	Princeton University Observatory, Princeton, New Jersey
Visvanathan, T. R.	Office of the Director General of Observatories, New Delhi, India
Vuorela, Lauri	University of Helsinki, Helsinki, Finland
Wallace, J. Michael	The Massachusetts Institute of Technology, Cambridge, Massachusetts
Warwick, James W.	University of Colorado, Boulder, Colorado
Webb, Willis L.	White Sands Missile Range, New Mexico
Williamson, David L.	Pennsylvania State University, University Park, Pennsylvania
Wood, Janet	Choteau, Montana
Wu, Shi-Tsan	University of Colorado, Boulder, Colorado
Yanowitch, Michael	Adelphi College, Garden City, New York
Yih, Chia-Shun	University of Michigan, Ann Arbor, Michigan
Yun, Twang-Sik	National Research Council of Canada, Ottawa, Canada