Reports of Research and Facilities Programs

1963

National Center for Atmospheric Research
Boulder, Colorado

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TABLE OF CONTENTS

FOREWORD

Reports of Research and Facilities Programs - 1963, contains brief technical summaries of the principal research and facilities efforts under way in each of NCAR's three scientific divisions. The summaries were prepared for internal use, for our own planning and coordination. We are aware, however, that the reports bring together a great deal of information on the current state and progress of the research of NCAR that is of interest to scientists outside of NCAR. Consequently, we are happy to provide copies of this document on request to research workers in other organizations. But we ask their indulgence while reading what is essentially an inside working paper in which, among other things, we have made no effort to preserve uniform modes of reporting between different divisions or activities of NCAR.

The reports, moreover, do not emphasize our effort to mount a coordinated interdisciplinary research attack on broad problems, even though many of the individual programs are sub-elements of such an integrated attack. However, this synthesis guides NCAR's approach; we regard the successful achievement of such an integrated attack on atmospheric problems as an essential element of NCAR's contributions to the atmospheric sciences.

Similarly, we have not, in spite of its high priority in our goals, described our visiting scientist programs in any detail, nor placed emphasis on the cooperative programs that provide ultimate justification for much of NCAR's effort. This, again, is consistent with the restricted aims of this particular document. However, I think it wise to mention the limitation explicitly, lest a casual reader be led to believe that we are not sensitive to our responsibilities for interaction, support, and service to the universities and to other private and public atmospheric science groups.

Our over-all purposes, as we interpret them, should perhaps be repeated 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 efficiently.

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.

Walter Orr Roberts

Walter Orr Roberts
Director

HIGH ALTITUDE OBSERVATORY

Introduction

During the year 1963, the staff of the High Altitude Observatory continued its efforts to increase our understanding of the sun, the sun's atmosphere, and the upper levels of the earth's and Jupiter's atmospheres. We have established a cooperative observing program with the University of Hawaii to improve the photoelectric measures of the corona; we completed a balloon-borne coronagraph to improve the photographic observations of the outer corona; and we have initiated a satellite coronagraph design to further improve our information about the sun's outer atmosphere. In Boulder, our laboratory spectroscopy work has accelerated, and the radio spectrograph has become a tool for investigating electron densities between the earth and Jupiter.

The report that follows describes our efforts and progress during 1963.

John W. Firor
Director

The Chromosphere

Chromospheric Structure

In the past year we made quite a bit of progress with the model of chromospheric structure which Zirin and Dietz began working on last year. This model indicates that the chromosphere is a very shallow extension of the solar photosphere, and that the higher excitation radiation seen in the chromospheric spectrum comes from spicules only.

Two new observational programs were carried out in respect to this chromospheric problem. The first was the program of high resolution H-alpha chromospheric photography done at Climax with a Halle filter installed at the Coude focus of the large coronagraph. Although this program could not be worked on until the high priority K-coronameter observations with the large spar were completed in August, we were able in the fall to obtain some good observations of the lifetimes and behaviors of spicules. Preliminary work with Tom Cragg and Robert Howard of the Mt. Wilson Observatory, using the Mt. Wilson spectroheliogram, had indicated that the spicules occur in clumps (which are called rosettes by J. M. Beckers, Sacramento Peak Observatory) or bushes on the edges of the chromospheric network. The Climax films show that the spicules are indeed in this position, and they may be seen to rise and fall on the edges of the network. The lifetimes of the spicules seem to be as long as 15 minutes, and we have not been able to detect any change in the basic chromospheric network structure in the course of the day. Further observations to see if the chromospheric network changes at all with time are now under way. Our films of the chromosphere taken in the center of the H-alpha line show a very rapid oscillatory motion in the center of the chromospheric cells, with a much shorter period than the lifetime of the spicules -- perhaps only a few minutes. This motion may be related to the oscillatory motion detected by J. W. Evans (Sacramento Peak) and Raymond Michard (Paris Observatory) in the photosphere. When one shifts to the off-band photographs, in the wings of the H-alpha line, this oscillatory motion is much less apparent, and the structure is dominated by the dark spicules on the edges of the cells. Recent work by Beckers, however, shows that even on off-band pictures it is possible to detect the oscillatory motion.

The second observational program in connection with the chromospheric structure was the obtaining of spectroheliograms in the 10830A line of neutral helium with the HAO image tube and the 60-ft tower telescope of the Mt. Wilson Observatory. This was a program which Firor and Zirin worked on together with Howard while lecturing at the California Institute of Technology in the spring. The 10830A line is a high excitation line and must represent the hotter component of the solar chromosphere. In May, Howard and Zirin succeeded in obtaining a number of high quality spectroheliograms which show the 10830A absorption on the disk of the sun comes only from the regions on the edges of the cells of the chromospheric network. Therefore the hot component of the chromosphere is indeed coincident with the spicules on the edges of the network cells.

During the year some other investigations of the helium radiation from the chromosphere were made at Climax, but were not very successful because of instrumental inadequacies. Some measurements were made of the 10830A absorption line on the disk, and one attempt was made to detect the D_3 helium line in absorption near the edge of the disk. The results were promising and will be carried forward with the new large spectrograph.

The Equilibrium of Barium in the Solar Atmosphere

During 1962 Tandberg-Hanssen began a study of chromospheric Ba II using eclipse and coronagraphic observations. During 1963 the emission from a number of prominences observed at Climax were studied to determine the occurrence and strengths of the various ionized barium lines.

The next step was to calculate the transition rates for the different excitation and ionization rates in the barium ion for different temperatures and densities. These rates were fed into an IBM 1620 program to determine the occupation numbers of the different levels in the BA II ion. A comparison of these calculations with the observed emission leads to the following conclusions:

The chromospheric resonance lines of Ba II are not formed under optically thin conditions. The faint lines indicate an emission scale height of about 215 km. The chromospheric emission can be accounted for in terms of local thermodynamic equilibrium (LTE) at a temperature of 6,000°K. Alternatively, the temperature may be as high as 8,000°K if one allows departure ($b \approx 100$) from LTE.

The Ba II emission lines in dense quiescent prominences are formed (as expected) under conditions far removed from LTE. Selective excitation conditions seem to be at play.

A Spectroscopic Study of Quiescent Prominences

Also in 1962, Tandberg-Hanssen initiated a study of quiescent prominences (see previous report). It was continued and brought to completion during this report year. The spectra of the prominence of March 26, 1960 were traced and central line intensities were measured. More than three hundred emission lines were recorded from this limb prominence in the wavelength region 3900-5900A. For comparison, one of the longest lists of observed prominence lines published(Richardson, 1950) has 109 entries in this same wavelength region. The plans for an "Atlas of Prominence Lines" were carried out and this Atlas will form part of a publication in a special issue of Astrophysica Norvegica appearing as a Festschrift for Professor Svein Rosseland (Institute of Theoretical Astrophysics, Norway) at his retirement this Spring.

The analysis of the prominence shows that the spectra of quiescent prominences are characterized by lines due to Sc II, Ti II and Y II while flare conditions seem to be selectively conducive to lines of Fe II.

Formation of Mg I Lines

Athay made an empirical and theoretical study of the opacities of the Mg I lines in the solar atmosphere in order to determine the effective heights of line formation. This problem is of importance in connection with the oscillatory motions observed at Caltech and Sacramento Peak. Athay's results indicate that most of the observations made at Sac Peak, thus far, referred to the lower and middle photosphere and not to the low chromosphere as the observers had assumed.

Athay also made a careful study of future solar observing techniques, both at eclipse and from space vehicles, and the relation of these techniques to unsolved problems of understanding the solar atmosphere.

The Corona

The White Light Corona: K-coronameter ("Koronameter")

A basic difficulty which has steadily plagued our full exploitation of the Koronameter in investigations of the longer term changes in the sun's electron corona has been the absence of sustained periods (extending over several months) of generally favorable observing weather. The extraordinarily stringent clear-sky conditions required for artificial eclipse observations dictate that coronagraphs be located at high altitude sites having frequent sky-cleansing precipitation of rain or snow. However, at Climax we seem to have too much of a good thing! Since the time the Koronameter was installed at Climax, in the fall of 1956, we have been able to obtain an average of only 5-10 days of observations per month. Far more complete -- in fact, daily -- observations are desired in order to adequately attack two of the principal problems of the sun's inner electron corona, namely: (1) construction of three-dimensional models of coronal features and (2) the correlation of the white light coronal "streamers" with geomagnetic storms, particularly of the recurrent type. Both of these problems are particularly worthy of intensive efforts during the years 1964 and 1965, as contributions to the International Quiet Sun Year's efforts.

It has long been thought that one of the high level stations in the Pacific, such as Mauna Loa or Mount Haleakala in the Hawaiian Islands, because of frequent dust-confining inversion layers and a high percentage of clear skies, might offer a fine site for coronagraph observations. Under the leadership of Professor Walter Steiger, the University of Hawaii has been steadily developing such a facility since the mid-1950's at the summit of Haleakala (10,000 ft elevation) on the island of Maui, and an actual observatory and supporting laboratory building were completed in the fall of 1962. As a cooperative venture between ourselves and the University of Hawaii it was decided that the Koronameter would be the first instrument to be installed at that site. Through the courtesy of Drs. Evans, R. B. Dunn, and Edwin W. Dennison, the designs of the Sacramento Peak 12-ft-long octagonal equatorial spar and photoelectric guider were made available to us, and duplicates were built for the Observatory. The Koronameter was removed from Climax in early August and by the end of September, Hansen and Garcia had made our first observations at Haleakala. During the ensuing three months of October, November, and December, the weather at the new site has fulfilled our highest expectations, and observations were possible during a total of 74 days. The long periods of clear weather at Haleakala should also permit monitoring of the corona on practically a continuous basis to search for abrupt changes before and after chromospheric events such as flares and eruptive prominences.

As is to be expected, the move to Haleakala has not been without problems. Some of the observing problems we experience at Climax have a counterpart on Haleakala in the form of small black bugs which swarm above the dome and scatter enough light into the Koronameter to destroy the observations. Since the bugs seem to fly during the best observing hours of the day they are indeed a serious and annoying problem. Hansen has sought the advice and cooperation of Hawaiian entomologists concerning the problem, and we hope to institute effective control measures in the near future.

that the material within the streamer can be replaced or exhausted in approximately that time and the escape velocity of the material along the streamer must be something like 30 km/sec at 0.3 solar radii above the limb. Perhaps significantly (or perhaps insignificantly) this is about the velocity which E. N. Parker (University of Chicago) would predict for the solar wind at such a height in the corona.

Coronascope II

The project which has come to be called CORONASCOPE II has as its purpose the observation of the solar corona for an extended period of time from a stratospheric balloon. The photographs obtained during the flight of this specialized coronagraph should enable us to answer many questions concerning the motion and lifetime of coronal features. At present we are in complete ignorance about how the corona above about 1.5 solar radii responds to transients such as solar flares on the disk. We also do not know which changes in the structure of the corona accompany such phenomena as type IV solar radio bursts. Also unsolved is the response of the corona to readjustments of the magnetic fields of sunspots. Green line (5303A) photographs of the solar corona near active regions have occasionally shown features called "whips" propagated through the lower corona. What manifestation, if any by about a factor of ten over that which would enter the objective from an ordinary, simple occulting disk. The entire instrument has been constructed in the High Altitude Observatory shops.

Of course, many secondary investigations had to accompany the construction of the coronagraph. For example, the question of a proper blackening agent for the walls and exterior of the coronagraph had to be found. A study at the Naval Research Laboratory suggested that many commercial paints would, in the semi-vacuum of the stratosphere, deposit effluent material upon the objective of the coronagraph and increase the scattered light level. Guiding amplifiers, timing circuits, and the like had to be environmentally tested in order to be sure that they would perform correctly in the stratosphere.

The most exciting test of the coronagraph was carried out in the 160-ft vacuum tunnel of the Kitt Peak National Observatory. After the instrument was completely assembled and adjusted, Bohlin, Lacey, and Newkirk transported it to Tucson in order to evaluate the instrumentally scattered light with a synthetic "sun" at one end of the vacuum tunnel. This "sun" was, in fact, a lens illuminated by a carbon arc. The vacuum was necessary in order to prevent scattered light from the air path from masking the scattered light in the instrument. The result of these tests was that the externally occulted coronagraph fulfilled our expectations with a radiance for the scattered light of only 10^{-9} that of the mean solar disk. This is to be compared with the skylight in the near infrared at 100,000 ft of the order of 3×10^{-9} and the corona at four solar radii from the sun which is approximately 10^{-9}. We thus have confidence that the equipment will be able to examine the corona from 1.5 solar radii out to nearly five solar radii from the center of the sun. The angular resolution of this coronagraph is approximately ten seconds of arc.

Although the CORONASCOPE II was to employ the guiding gimbals which were used for CORONASCOPE I and STRATOSCOPE I, a considerable improvement of the guiding accuracy over these earlier experiments was necessary. A guiding accuracy of ten seconds of arc peak-to-peak excursion was our goal -- an improvement of about a factor of five over the guiding servos used before. Extensive modification of the guiding system was made in the electronics shop; mechanical changes such as the substitution of rollers for gears were also made. Late in the year, tests were accomplished which showed the goal of ten seconds of arc guiding had been achieved.

The operational aspects of CORONASCOPE II also posed some unexpected difficulties. The original plan was to carry the system to 100,000 ft on a 2.94-million-cubic-foot polyethylene balloon. Unfortunately, test flights of this vehicle in September and November at NCAR's Palestine site both ended with the bursting of the balloon at the tropopause. Although many reasonable hypotheses for the rather frequent rupture failure of polyethylene balloons under moderately heavy load have been offered, the cause of the failure and its remedy are still unknown. It may well be that the polyethylene balloon is an intrinsically marginal vehicle for carrying loads in excess of 1,000 lb above 100,000 ft and any slight departure from optimum design or material strength brings about disaster. In order to carry out the objectives of CORONASCOPE II it seemed wisest to transfer the program to a Mylar-scrim balloon, which has several times the material strength of the polyethylene vehicle, and, unfortunately, several times the cost. However, the transfer was necessary if we were to accomplish the first flight in the foreseeable future. As of the closing of the report period, the CORONASCOPE II system, including the balloon, the coronagraph, and the guiding, is complete. It is expected that the necessary adjustment and calibration procedures will allow its first flight to be accomplished early in 1964.

Satellite Coronagraph

Under the direction of Eddy with the assistance of Newkirk, the Observatory is preparing an externally occulted coronagraph to fly in the Advanced Orbiting Solar Observatory due to be launched at the time of the next sunspot maximum. In fact, the CORONASCOPE II system should be considered as a prototype for this more advanced coronagraph -- an instrument which will be able to keep the corona under nearly constant surveillance for periods of several months. In several ways the satellite instrument must be a violent departure from the balloon-borne instrument. Firstly, the satellite coronagraph must face a vastly more rugged environment. Not only does it have to operate in a nearly perfect vacuum, but it must be designed to withstand the deteriorating effects of micrometeors and X-ray and ultraviolet radiation. Secondly, the data are not conveniently recovered in the form of a roll of photographic film. Perhaps the greatest problem we face is that of the transmission of the image of the corona gathered by a vidicon or a scanning photoelectric cell to the ground for analysis.

Eddy began work late in the year on a design study for this instrument. The instrument considered will be capable of recording changes in brightness, extent, and polarization of the outer corona (2 to 6 solar radii), both long-term (days to months) and short-term (minutes), with angular resolution of one arc minute or less.

At present the only optical observations of the outer corona more than a solar radius above the limb are those obtained during natural eclipse, since the steep gradient of coronal intensity and the limitations of instrumental and atmospheric scattering in conventional coronagraphs combine to restrict observations to the innermost regions. Instrument scattering limitations can be overcome by careful design of a multi-disk external-occulting coronagraph; atmospheric scattering can be beaten only by lifting the coronagraph above all or part of the atmosphere by rocket, balloon, or satellite. Of these, the satellite is superior in several ways. The coronal observing time provided by rocket flights is too short to constitute an advantage over eclipse observations.

Only an orbital coronagraph can fulfill the mission of continuous coronal coverage. With sky brightness reduced to the stellar background, observations of the faint outer corona are limited only by instrument scattering. More important, a coronagraph in orbit is a coronagraph on station and ready to record the now unknown variations in the outer corona, whatever their time scale may be.

The basic optical system of the orbital coronagraph will be a scaled-down version of the CORONASCOPE II instrument, modified for photoelectric read-out and redesigned to meet the peculiar problems of satellite operation, including launch stress, meteoric pitting, and lens fluorescence. Three photodetection devices were considered for the orbital coronagraph: a scanning photomultiplier, a mosaic of silicon photo cells, and a video system. Our preliminary conclusion is that of these possible schemes only the video system provides the capability of meeting the scientific objective of rapid coronal photometry with angular resolution sufficient to detect coronal motions and transient features.

In the coming year we hope to work with a suitable subcontractor on an engineering study of video and telemetry systems to minimize the power and data storage requirements of the orbital coronagraph. When clear results are obtained we shall proceed to subcontract the building of a breadboard model of the satellite instrument. Concurrent with this study, and within the High Altitude Observatory, we shall begin the redesign of the optical system, making use of the experience gained in the CORONASCOPE II flights.

The Emission Line Corona

The Shape of Coronal Line Profiles

Billings, Moore and Lilliequist studied the influence of conditions which might be expected to be present in the corona on the shape of line profiles. First they investigated the distortion of the profiles from Gaussian that would result from oscillatory motions in the corona. Similar distortions would be created by radially inward or outward flowing gas in cylindrical configurations in the corona. Next they considered the distortion arising from a range of temperatures along the line of sight, and concluded that the latter effect was precisely opposite the former -- hence it would be possible to have motion and temperature-range distortions exactly canceling one another. Lilliequist has reduced the rather difficult computations involved in measuring small distortions of coronal line profiles to a computer operation.

Coronal profile shapes that have been studied to date have shown a small amount of motion distortion in very sharply-defined features, but most of the distortions have been characteristic of variations of temperature along the line of sight. There is some evidence of a periodic fluctuation of these distortions. The entire problem of deducing coronal characteristics from profile shapes is in its infancy and is a subject for continued research by Billings and Lilliequist.

Oscillations in the Corona

The Climax observers photographed two sequences of coronal spectrograms in which the coronagraph remained directed at the same position in the corona for many repeated spectrograms. In one case an exposure was made every two minutes, and in the other case, every thirty seconds. Billings and Lilliequist found that when high-quality tracings of a feature on these spectrograms were superimposed so as to match the Fraunhofer lines in the scattered light continuum, very small differences in the profiles of the same feature could be detected between one exposure and the next. Such comparisons, carried out on the two-minute-interval spectrograms suggested a periodicity in the line-of-sight motion of about 300 seconds and an amplitude of less than 1 km/sec. The effect was difficult to confirm, however, because of the near equality of the observing interval to one-half the possible period. Very careful measurements from the 30-second-interval spectrograms revealed again the 300-sec periodicity, with an amplitude of about 0.4 km/sec. It is significant that entire profiles are rarely displaced from each other. Rather, the motion is displayed as a fluctuation in one or the other wing of the profile, indicating that only part of the material is in motion, or that the observed motion is the uncompensated residual of a random motion along the line of sight. Excellent tracings are available for further study of this phenomenon.

Coronal Condensation Analysis

K. Saito, while visiting HAO from the Tokyo Astronomical Observatory, carried out the analysis of his observations of an intense coronal condensation during the February 5, 1962 eclipse. Billings collaborated in the analysis. Polarimetric observations made it possible to construct a three-dimensional model of the condensation. Also, Saito and Billings attempted to deduce a magnetic field configuration from the distribution of matter, and in certain tubes of force to compute a reasonable temperature distribution, solar wind, and the energy input.

Rust and Zirin carried out a study of the correlation of the polar coronal line with the magnetic field intensities measured at Mt. Wilson. Although this problem is often lost in the jungle of statistical analysis, there appears to be a fairly clear-cut relationship between higher coronal intensities and higher magnetic field values. In particular, in the last few years the south polar field of the sun has virtually disappeared, and so has the coronal radiation from that region. The north polar field still exists, and the coronal lines are still seen in that area. It is, however, difficult to separate the occurrence of individual regions of activity from the existence of a general polar field, and we face the same problem in analyzing the coronal data. Work in this direction is continuing.

Ultraviolet Spectrum

During the year a new high quality ultraviolet spectrum of the sun down to 40A was obtained by H. E. Hinteregger of Air Force Cambridge Research Laboratories. Quite a bit of work on identification of lines in this spectrum was done by Dietz and Zirin. About 30 new lines, mostly coronal lines, were identified. The strongest lines, however, remain unidentified, but we think they are due to various coronal ions of iron. It may be that the laboratory production of these lines will yield the most direct identification.

Vacuum Spectrograph

House continued his study of the spectra of highly ionized atoms to aid in the identification of lines observed in recent rocket ultraviolet spectra of the sun. Since the last report, the grazing incidence vacuum spectrograph has been put into operation. This instrument, which is briefly described in the previous report, is a rocket spectrograph converted to laboratory use, and was loaned to HAO by Dr. Hinteregger.

Two types of light source capable of producing radiation in the 60-1100A region have been used in conjunction with the spectrograph. The first source, mentioned in the 1962 report, is the vacuum-sliding spark. Comparison of the gross features of the spectra produced by this source with a non-local thermodynamic equilibrium (non-LTE) ionization calculation indicates an effective ionization temperature of about 10 ev. This is not a high enough energy to create the typical ultraviolet coronal ionization being sought.

In June, 1963 the spectrograph was moved to the Project Sherwood establishment at Los Alamos, New Mexico, to use a high energy plasma device, Scylla III, as a second light source. This work is being done in cooperation with Dr. George Sawyer of Los Alamos. The plasma is produced in deuterium gas by a fast theta-pinch magnetic compression driven by a condenser bank storing 280 kilojoules at 70 kv. Selected impurities are added to the plasma, and by comparison of the spectra with and without the impurities, the lines due to the added element can be identified.

Several impurities are under study, perhaps the most important of which for solar physics is iron. However, the first definitive results are based on the analysis of the spectra of highly ionized neon. Wavelengths of 16 transitions in neon VII and VIII previously unobserved have now been determined by House with an accuracy of 0.1A. The temperature required to produce the observed ionization is of the order of 100 ev.

Future development of the project will follow two lines. First, an improved version of the vacuum-sliding spark capable of operation at 60 kv will be developed. This will test the ultimate capabilities of this type of light source to produce high ionization states of various atoms. Second, the construction of a fast theta-pinch in our laboratory will provide the future program with a very efficient and flexible device that can serve not only as a light source for spectroscopy, but also as a source for a variety of studies in plasma physics. The condenser bank being considered will store 25 kilojoules at 25 kv, and the design is being worked out with the cooperation of our colleagues at Los Alamos.

Theoretical Radiation Studies

In an attempt to understand the origin and the transient nature of the spectra being studied with the vacuum spectrograph, House undertook a theoretical study of the conditions in the light source. The first task in this study was to develop a computer program to solve the time dependent equation of statistical equilibrium for any element. This first program is crude in the sense that each stage of ionization is represented by only a ground state and a continuum; however, n stages of ionization are considered simultaneously. As input to the program one must have the time behavior of the electron temperature and density. Since the electron temperature and density are closely coupled with the radiation properties of the plasma, specifying them independently is not completely self consistent. Improvements will be made on this program in the future.

Several facets have developed from the above calculation. Time independent solutions to the statistical equilibrium equations were needed as initial values for the solution to the time dependent problem. Therefore, the equilibrium solutions for all elements from H to Fe for a wide range of temperature and density were calculated.

Helium is an element frequently used in plasma devices and the study of the helium radiation provides an important diagnostic tool for probing the plasma. Fisher and House have completed the solution to the statistical equilibrium equations for helium in the laboratory plasma condition. The calculations treat seven bound levels of He I and five bound levels of He II simultaneously. Departures from LTE are found to be large, which invalidates certain LTE calculations frequently used in determining temperatures of plasmas.

One final calculation which is an outgrowth of the original time dependent calculations has been done for the corona by House and Billings. The time dependent computer program mentioned previously was modified to test the possible significance of time dependent ionization processes which might occur as a shock wave passes through the corona. They assumed that a series of shock fronts selectively heat the ions and that these shocks can be represented by a train of delta functions in ion temperature. No specific details of the shock structure other than the period and peak ion temperature are used. The electron temperature is calculated taking into account the transfer of energy from the ions and the subsequent loss of electron energy through coupling with the radiation field. With the electron temperature described, the time dependent equations of statistical equilibrium for iron are solved. Comparison of the results of the calculation with coronal observations by Billings and Lilliequist are in progress.

Solar Activity

Flare Prediction

Billings and Avery have been investigating the possibility of predicting the likelihood of the production of flares by an active region in the sun on the basis of the H-alpha spectrograms of the region on the east limb. These spectrograms have been chosen as a means of flare prediction since they constitute the first spectrographic observation of the region that is readily available for analysis. Indices which measure roughly the violence of prominence motion in the region appear to be fairly good indicators of subsequent flare activity. It is interesting that such indices are almost as good for prediction of flare activity occurring a week after east limb passage as for prediction of east limb flares.

Solar Radio Bursts

Warwick's efforts to determine the positions of solar radio emissions have continued during the year. Wightman has programmed the synthesis of the interference fringes for each record we have taken. From this synthesis, which was carried out completely by computing machine, we plan to construct overlays to permit direct scaling of burst positions during complicated solar events. In a sense, this procedure duplicates the procedure followed automatically by the interferometers at Dapto, Australia. Our previous determinations of positions have been based on scalings of the records at very closely spaced time intervals. This perfectly objective and theoretically correct procedure has, in the case of the most interesting and complicated solar events, led us to rather poorly-defined conclusions. In addition, we have fixed-frequency data at 18 and 36 Mc/s for the same events recorded by the spectrograph. The importance of the fixed-frequency observations is that their base lines are at rather large angles to the baseline of the spectrographic interferometer. Lund and Warwick are analyzing these measurements in the hope that they will be able to resolve possible lobe ambiguities inherent in the spectrographic observations, as well as to make some two-dimensional position determinations.

Flares and Prominences

The large coronagraph- H-alpha arrangement described in connection with chromospheric studies was also used for observations of flares and prominences. During September the Climax staff and Zirin were fortunate in obtaining fine films of an active region which produced a number of flares. Although quantitative analysis has not yet taken place, we have already learned a great deal from these films about the different kinds of flares. The films show that the general structure of an active region is extremely stable from day to day and the same type of flare repeats over and over again. Among the different types of flares observed are the explosive flare, when a large region erupts all at once, usually triggered by a small flare in another part of the active region; the umbral flash, when a fast bright disturbance comes from the center of the umbra; and the simple brightening usually accompanied by a surge. In the film, waves of excitation, which may be magnetohydrodynamic waves, are seen to travel back and forth across the active region. It seems that many flares are triggered by such waves.

Zirin has compared the many small flares seen on the September films with the radio records obtained by the HAO radio spectrograph. Many of the small brightenings correspond exactly with type III bursts, and further work in this direction is proceeding.

The work on the reduction of the observations of the November 20, 1960 flare has been completed by Zirin. This flare was a classic explosive flare on the limb of the sun. It was accompanied by a significant increase in ground-level cosmic ray intensity. The coronagraph spectra show the very high excitation in the post-flare coronal condensation. In particular, we have found that the spectra indicate that the preponderance of the material in the flare is at coronal temperatures. In some of the spectra it is possible to study the emission lines of Ca XV and He II in the same region, along with the continuum radiation scattered by the electrons. Large increases in the ionized helium emission occur without any perceptible change in either the coronal or the continuum scattering radiation. This means that only a small amount of the material is necessary to emit the ionized helium line, and the same conclusion probably applies to the hydrogen and other radiation. It seems that only a very small amount of material is necessary to produce the observed flare radiation, and the preponderance of the material is in the coronal state, where it produces the well-known ultraviolet radiation. The November 20 flare was an excellent chance to study this because the active region was over the limb of the sun, and only the occurrences in the solar atmosphere could be seen from the earth.

The program of analysis of Climax's prominence spectra was carried on during the year, and we obtained for the first time a good set of spectra of the higher Balmer and Paschen lines in a prominence. These were analyzed by Mao, and it was found that the Balmer and Paschen lines have the proper ratio to one another, in contradiction with the results of the 1952 eclipse derived by House, Athay and Zirin. A number of comprehensive prominence spectra have been obtained, and are being analyzed by Glasco. The spectra of the July 20, 1961 flare have been under analysis by Acton.

The year saw the completion of the theoretical phase of researches on resonance polarization. The program was outlined in last year's report. However, in the final analysis, Hyder was able to draw some conclusions on the nature of the general solar magnetic field. These conclusions were based on Lyot's observations of systematic trends in the orientation of the E-vector of emission line polarization as a function of solar latitude. Lyot found that this vector rotated with respect to the tangent to the solar limb. At low solar latitudes, the vector is parallel to the limb, but at high latitudes it is at angles of 30 to 40 degrees. Individual prominences showed wide variations from this over-all trend, and moreover, during the year there appeared results of a German program of observations that casts doubt on the very existence of Lyot's effect. Nonetheless, Hyder's interpretation of Lyot's observations suggests the possibility that the general solar field lies along parallels of solar latitude. It would appear that the solar general field is toroidal in character. If this is the case, one might expect that the sense of the field would change with the sunspot cycle. Lyot's observations were made in the mid-thirties. Reckoning on the 22-year solar cycle, we are now in the opposite 11-year cycle to the one during which Lyot made his observations. Therefore, it is of extreme interest to establish whether the effect observed by Lyot is currently reversed in sense. This prediction of Hyder's thesis is subject to immediate confirmation, and in fact, if not tested now, a wait of another half cycle, e.g. 11 years, will be necessary. Hyder therefore arranged with his new institution, UCLA, to permit him to visit Climax for two months in early 1964 to attempt to make the crucial observations.

The Solar System

Radio Studies

Collins has engaged on a program of determination of flux densities for the radio stars Cas A and Cyg A. We have, in addition to the 18 and 36 Mc/s interferometers, data from an interferometer at 8 Mc/s. The major obstacles to the success of this program have been the careful calibration of equipment parameters such as line lengths, impedance matching, and receiver-gain characteristics on the one hand; and of antenna gain and pattern parameters on the other. For each of these three interferometers, the antenna is a very simple array of dipoles over a ground plane. We have hopes that, given our synoptic data to permit us to evaluate ionospheric parameters, and these simple antennas, it will be possible to establish absolute fluxes as well as, with perhaps higher precision, relative fluxes of these two bright radio stars. It has become clear that the 8 Mc/s interferometer is of absolutely minimum gain for making satisfactory measurements of the radio star. It is quite probable that we have detected Cas A on a number of occasions. Nevertheless, our antennas, which have a gain of the order of ten decibels over a dipole, need to be considerably larger for really effective measurements of this type. We do not, however, plan these larger antennas at our present site.

As in the preceding year, we have spent a great deal of effort on the radio emissions from Jupiter. A number of new effects became apparent during the year. Although we had previously supposed that our data were effectively played out insofar as new effects are concerned, that has proven decisively to be not the case. In particular, George Dulk (graduate student at the University of Colorado) and Warwick have been able to isolate the Faraday effect on numerous records from both 1962 and 1963. It has been well known for many years that Jupiter's decametric emission is polarized, in the right-handed sense and often elliptically, with an axial ratio of the order of two or three to one. Such radio waves, falling on the earth's ionosphere, are broken into the two equivalent circular states of polarization. These two waves, the extraordinary and ordinary modes, propagate along separate ray paths through the earth's ionosphere and are then recombined, but with different phases than they had external to the earth. The result is that the total wave is again an ellipse, with the same axial ratio as outside the ionosphere, but with its major axis rotated through an angle proportional to the total electron content weighted by the longitudinal component of the magnetic field along the average ray path. Of course, this effect takes place everywhere in space where a magnetic field and electrons are simultaneously present. In principle, we might expect that a large Faraday effect occurs in Jupiter's environs close to the physical source of the emission itself. The remarkable feature of the observed effect is the precision with which total content can be measured. For example, at 30 Mc/s the total number of rotations of the major axis is of the order of 10 to 20. The actual figure is determined in our measurements to a precision of 5 per cent or better. This is significantly higher precision than is obtainable from the direct reduction of ionosonde records, for example, and arises from the fact that our measurements are essentially measurements of the frequency of Faraday nulls, and frequencies can be measured with high precision. It turns out in one case that the ionospheric total content measured by combined observations from the ground and the ionosonde satellite Alouette accounts for the entire Faraday effect to within the precision of measurement. In other words, there are no electrons and magnetic field left over for Faraday effect at Jupiter.

This is a disturbing conclusion, and can be resolved in several ways. For example, the radiation may be generated in a region of very low electron density. This seems to be inconsistent with most of the models of the emission that have been proposed. A second possibility is that the emission is generated in just one magneto-ionic mode. Of course, the Faraday effect depends on the resolution of a wave into two characteristic modes; if only one exists in the radiation at Jupiter, then no modification of the mode will occur as the wave propagates through Jupiter's ionosphere. The difficulty with this point of view is simply that for most directions of propagation the characteristic mode of radiation is circular, not elliptical.

A final, very interesting conclusion may be possible from these data. With 15 or 20 complete rotations of the polarization ellipse, the total number of degrees is of the order of 10^4, and this number can be ascertained to a precision of the order of one per cent. In that case we can determine the orientation of the polarization ellipse at the source of the emission to about a 100-degree uncertainty. This is such a large angle as to be of limited value. On the other hand, it may be possible, in a few instances where the data are of unusually high quality, to establish the total rotation to a precision greater than one per cent. If this indeed proves possible we may be able to follow the rotation of Jupiter in terms of the plane of polarization of the decametric emission. This could be decisive information with respect to the mechanisms of generation of the bursts.

A second major conclusion has been possible during 1963. During a visit to C.S.I.R.O. in Sydney, Australia, Warwick discussed recent decimetric observations made at Parkes by J. A. Roberts and Max Komesaroff. In particular, these observations exhibit the change in orientation of the plane of vibration of Jupiter's flux at 20 cm as Jupiter rotates. We would expect that this variation was sinusoidal with a half amplitude equal to the angle between Jupiter's magnetic moment and rotation axis. In fact, this interpretation of the Caltech observations led D. Morris and G. L. Berge, both of Caltech, to the first published discovery of the obliquity of Jupiter's moment. The remarkable feature of the Australian observations, which are of unprecedentedly high precision, is that they show that the variation is significantly non-sinusoidal. The total range in position angles is 22 degrees, suggesting a value of obliquity of 11 degrees. On the other hand, the crossover points where Jupiter's magnetic moment passes between the axis of rotation and the direction to the earth, lead to values of the obliquity of 8 degrees at the counter-clockwise crossover, and 13 degrees at the clockwise crossover.

There is, of course, complete ambiguity as to which of these three values of the obliquity angle to choose. It is possible, however, to interpret the asymmetries in terms of the occultation of Jupiter's radiation belts by the bulk of the planet itself. It is not sufficient that the radiation belts should be centered at the centroid of mass of the planet. In that case, even though not perfectly sinusoidal, the plane of vibration should at least describe a symmetric curve at the two crossovers. Instead, it can be shown that it is necessary to displace the moment along the axis of rotation by a significant amount. In fact, the displacement must be towards the southern rotational hemisphere of Jupiter. The sense of asymmetry would be just reversed if the displacement were into the northern rotational hemisphere. Warwick considers this to be a confirmation of his theory of the decametric emission which was outlined in last year's report. During the December AGU Meetings in Boulder, it was reported that new measurements by Morris and Berge have suggested that the centroid of the decimetric emission is, in fact, displaced in just this same sense. These are direct observations rather than interpretations of the occulting effect described above.

Finally, at year's end, we received reports from the MIT group, under the direction of Bruno Rossi, of X-ray emissions from the cosmos at a position not inconsistent with the source being the planet Jupiter. Although the MIT group did not so interpret their observations, Warwick has made an attempt to estimate from his theory of the decametric emission what the intensity of X-radiation ought to be. The amount predicted is definitely less than observed by the MIT group, although not by such a very large amount as such matters go (only 1000-fold!). The wavelength of the emission is just right, in the range 1-10A. If such measurements can be confirmed, they will establish in a more direct way than the previously attempted observations of Jupiter's aurora the existence of particle precipitation there.

During the year a number of cooperative programs of Jupiter research just grew out of the widening community interest in this type of research. In the first place, we have compared data with William Sherrill of the Southwest Research Institute in San Antonio. He makes detailed polarization measurements during bursts of Jupiter. We can supply details of the spectrum and time variations from a different location. Secondly, we have compared records taken by William Erickson of the University of Maryland. His equipment at Clark Lake, California has an enormous collecting area, and permits a very sensitive determination of the cut-off of Jupiter emission outside of the drifting bands observed with the spectrograph in Boulder. In most of the records taken at Clark Lake, cut-offs observed at Boulder are duplicated by a complete cessation of emission at Clark Lake. It would appear that Jupiter's emission goes down by something of the order of 30 decibels in a frequency range of only a megacycle or so. Thirdly, we have corresponded with Richard Kaufmann of the Air Force Special Weapons Center, Kirtland Air Force Base, Albuquerque, New Mexico. Kaufmann has detailed programs for computation of the synchrotron emission from electrons trapped in dipole magnetic fields. At year's end, this program still is not in our hands but we expect to be able to check the analysis described above of the decimetric asymmetries. In the fourth place, we have advised and discussed with the Air Force Cambridge Research Laboratories radio astronomy group, in particular R. Straka, on the use of their dynamic spectrograph to observe Jupiter. In September, after consultation with us, they have succeeded in observing a number of Jupiter events which also, for the most part, appear in the Boulder data. The first few comparisons have shown striking similarity and confirm the conclusions we have drawn concerning our dynamic spectra. Finally, as a result of Warwick's visit to Australia, the Jupiter group at Sydney and we are exchanging data on events that we have observed simultaneously. There is an hour or two a day when they are just beginning observations as we are just ending ours. What will result from this is as yet undetermined.

Planetary Photography

A short but moderately successful program of planetary photography was carried out by Firor and Zirin, together with Guido Munch of Mt. Wilson and Palomar Observatories, with the 200-in. Palomar telescope. Photographs of both Saturn and Mars were obtained at the Coude focus of the 200-in. with the HAO image tube and a Wratten 87 c filter, giving an effective wavelength of about one micron. The Saturn pictures do not differ much in appearance from those in visual light, but the Mars pictures appear to show surprisingly large limb darkening. Further, if there were any chlorophyll-bearing material on the planet, one should expect bright radiation in these wavelengths. Instead the planet appears dark in all the regions normally identified as "greenish" in the visual region of the spectrum. It is hoped to carry on this program further when more time is available. Work of a similar nature was carried out by Eddy with the 16-in. Climax coronagraph; however, it was discontinued because of the slow speed of the instrument. A number of photographs of Jupiter were obtained, however.

Upper Atmosphere

Geomagnetism and Ionosphere

Matsushita investigated three problem areas during the year. The first area concerned sporadic E, its basic behavior and its possible correlations with ionospheric currents. In general, he found that sporadic E shows definite lunar tidal effects and also is strongly affected by electromagnetic drift effects. Further, sporadic E shows correlations with ionospheric currents, but the details of the correlation are a function of latitude.

In other studies related to ionospheric currents, Matsushita tried to ascertain the connection, if any, between micropulsations, sudden commencements and ionospheric currents. He concluded that in many cases one must invoke such currents to explain the geomagnetic phenomena.

The third area studied was the detailed events that go to make an ionospheric storm. Although a complete picture does not seem possible at this time because of insufficient data on the upper part of the F_2 region, the data which do exist seem to indicate that the electron density decreases at high latitudes while it increases at low latitudes. Although the decrease at high latitudes has been previously explained, the low latitude increase is not understood at present.

RajaRao synthesized the quiet day (S_q) variations in horizontal and vertical intensities of the geomagnetic field along the equatorial electrojet at different longitude zones, making use of the daily ranges on international quiet days at Jarvis, Addis Ababa, Trivandrum and Kodaikanal during the year 1958. There is a seasonal variation in the intensity of the electrojet, with pronounced maxima in the equinoxes and minima in the summer and winter months. Larger diurnal variation in the vertical force prevails to the south of the center of the electrojet. Individual fluctuations in horizontal and vertical forces recorded during magnetic storms in the IGY period, at the equatorial electrojet stations Trivandrum, Jarvis, and Koror have been normalized to the magnitudes of the corresponding fluctuations at low latitude stations outside the electrojet. The plot of the mean normalized values against local time indicates a mid-day intensification of the storm time fluctuations, similar to the daytime enhancement of the normal S_q field. This intensification has been explained as a consequence of the DP (disturbance polar) currents flowing down to the magnetic equatorial region and getting intensified by the presence of anomalously large conductivity in the ionosphere in the electrojet region. The abnormal behavior of the variations in the vertical force during the storms at low latitudes at Honolulu, Muntinlupa, Kodaikanal and Annamalainagar, viz. variation with respect to horizontal intensity during storms being opposite in sign to the variation on a quiet day, has been explained as being due to the northward shift in the focus of the overhead electric current system.

Ashour has studied a number of problems related to the production of currents in the ionosphere. In particular, he has worked out the electromagnetic induction for some specific models -- the circular disk, infinite plane with a circular hole, and the spherical cap. He has been able to include in his study some of the effects of finite and non-uniform conductivity.

Chapman completed a study of the energy of magnetic storms -- a study of the additional energy of the magnetic field in the cavity formed in the solar plasma, during the first and second phases of magnetic storms. In the case of the main phase, the ring current has both kinetic and field energy; Chapman found the former to be the greater.

Chapman and S.-I. Akasofu of the Geophysical Institute, University of Alaska, continued their studies of the aurora and geomagnetic storms. They demonstrated that changes of solar plasma pressure, manifested by the storm sudden commencement or sudden impulse, do not always lead to the growth of the ring current, polar magnetic substorms and auroral substorms. They inferred that the solar plasma stream must have important characteristics additional to its momentum density. In addition, they were able to show that the growth of the ring current belt within the magnetosphere during magnetic storms is closely related to the equatorward shift of the latitude in which the aurora is seen. During the storm of February 11, 1958, this latitude became as low as 50° geomagnetic in the American sector. The ring current field present during the main phase of great magnetic storms was shown to have two parts, ascribed to two belts at different distances from the earth's center; the inner belt decays much more rapidly than the outer one. Later Akasofu, in conjuction with C. E. McIlwain of the State University of Iowa, proposed that the inner belt is produced by neutral hydrogen atoms that come to the earth with the solar plasma, pass unretarded to the outer confines of the ionosphere and there, losing an electron, become protons and form the inner belt.

Kendall and Chapman found a remarkable solution of a problem of hydromagnetics, in which in the region around a neutral line in a magnetic field there is progressive conversion of magnetic field energy into kinetic energy of a perfectly conducting incompressible liquid.

Radio Star Scintillation

The spectrograph seems to have completed its basic contributions to radio star scintillation phenomena. The preliminary results of this research appeared in the 1962 report; in 1963 the completion of the first detailed report was achieved. Donald Singleton, visiting from the University of Queensland, Brisbane, Australia, finished several significant pieces of research on the scintillation data. After classifying carefully the various types of scintillations we observe, Singleton thoroughly studied their statistics over the last several years. This project was somewhat, but not decisively limited by the incompleteness of observations in sidereal time. Perhaps the most significant result of this project was his fully decisive verification of our conclusions on the importance of broad-band scintillations at low frequencies. Furthermore, he verified the general nature of source motions during scintillations, in time and in frequency. Finally, he discovered a very interesting connection between sidereal time and the sense of source motion as a function of frequency. With this experimental result in hand, he has been able to establish the statistical orientation of the ionospheric drifts or winds. This appears to be in the direction of the isoclines of the earth's magnetic field.

Singleton also undertook a more thorough investigation of the behavior of our interferometer to refractive variations in the wave front from a radio star. From this analysis, he has been able to show there is a limitation on the distance determinations carried out by Warwick last year. In particular, he finds that the distance determination is indeterminate for a certain range of azimuths for the wind vector. This result perhaps is not too surprising inasmuch as we can measure only one angular component of source motion in any event. It does suggest that further researches of this type would be benefited by a third antenna which would provide absolute directions of the wind vector.

In connection with our program of analysis of scintillations, we computed synthetically amplitude distributions for scintillations resulting from a small number of irregularities. As is well known, for a large number of irregularities amplitude distributions in scintillations should approach a Rayleigh distribution. Since our data indicate that very few irregularities contribute to any given scintillation, we have thought it worthwhile to restrict the distributions to a small number of irregularities, say less than five or six. Results of this program have been run and plotted, but, at the end of the year, are not yet analyzed.

Atmospheric Tides

The spherical harmonic analysis of the 24-hourly surface pressure wave has been completed by Haurwitz. But its interpretation requires further theoretical calculations of the 24-hourly oscillations expected in a vibrating system of the structure of the atmosphere which have not yet been completed because of other work to be mentioned below.

Early in 1963 the Aerological Commission of the World Meteorological Organization appointed a Working Group on the Synthesis of High-Atmospheric Data. One of the charges to this working group was the preparation of a report on periodic motions in the high atmosphere, specifically up to those heights which are still low enough to be of meteorological interest (approximately up to 100 km above the earth). Haurwitz undertook the preparation of this report which is now in the hands of the Aerological Commission for publication. The preparation of the report required a new critical evaluation of the available data on tidal oscillations in the high atmosphere.

Although the 12-hourly pressure oscillation at the earth's surface is reasonably well mapped and shows a fairly regular distribution there are local peculiarities which are presumably caused by geographic features. One of these is the behavior of the oscillation as it encounters the mountains in the western part of North America. For the United States the amplitude and phase distributions of this oscillation have been mapped in considerable detail; but data have become available only recently which enable the same to be done for Canada. Such a study has been undertaken by Haurwitz and Avery. This region is further interesting because it contains one of the amphidromic points resulting from the superposition of the migrating and standing semidiurnal oscillations. There the amplitude vanishes while the lines of equal phase rotate around this point. This is the first time that the location of one of these points could be fixed by observations.

The semidiurnal pressure oscillation shows peculiarities in its seasonal behavior. An attempt to explain these phenomena and their differences at different locations has been started in collaboration with Dr. W. Schwerdtfeger of the University of Wisconsin.

The determination of the lunar semidiurnal tide has been continued. So far, the lunar tidal pressure variation and its seasonal variation has been determined at three stations in the continental United States and at three stations in the Caribbean area. Unfortunately, the determination of lunar tidal winds, so far only derived approximately by Chapman for Mauritius, has not yet been very successful because the relative errors of these determinations are too large. It will probably be necessary to use only reasonably quiet days when the wind velocities are small. In order to do this it is planned not to have the hourly mean values computed at the National Weather Records

Center in Asheville as heretofore, but rather to obtain the data on copies of the punched cards and perform all the necessary calculations here. This procedure would permit greater flexibility in selecting the data than is now possible.

In connection with the report on periodic motions in the high atmosphere, a brief survey of the role of internal gravity waves in these layers was also given by Haurwitz. The present theory and its application to the phenomena in the high atmosphere do not take into account the possible effect of large-scale wind systems and of the existing vertical temperature gradients. Haurwitz plans to investigate how these factors may modify the present theory and its application to the observed phenomena.

Chapman completed a study of the daily variations of atmospheric pressure at Kimberley, South Africa, in conjunction with Mr. W. L. Hofmeyr of the Weather Bureau of South Africa; the solar daily variation was analyzed into its first four harmonic terms, and the lunar atmospheric tide was determined.

Atmospheric Ozone

During the past year our ozone research activity has been divided into two complementary parts: one dealing with the processing and analysis of data concerning the distribution of total ozone, the other dealing with the photochemistry and energetics of molecular oxygen and ozone, particularly in the mesosphere.

The collection of ozone data for the post IGY-IGC period continues. Daily and mean monthly ozone values for this period for all observing stations have been put on punch cards so that the data can be made readily available for processing by ourselves and other interested research workers. The data for subsequent years are also being collected and punched.

Previous analysis of the ozone data for North America indicated marked longitudinal variations in the total ozone pattern with strong latitudinal gradients present during the winter and spring and relatively weak latitudinal gradients present during the summer and fall.

These mean seasonal maps have been supplemented by mean monthly ozone maps for the period July, 1957 - December, 1959.

A preliminary analysis was made by London of the range and phase of the annual ozone variation for stations in both northern and southern hemispheres. In this preliminary analysis it was found that the range of the mean monthly total amount of ozone from maximum to minimum increases with latitude in both hemispheres. In the Northern Hemisphere the maximum range is over 200 milli-atmcm. (200×10^{-3}cm at STP); this represents an annual variation of about 50 per cent of the mean amount of total ozone found at about 80^{o} latitude. The annual range seems also to show some longitudinal variation which is consistent with the distribution of total ozone. That is, the range is slightly higher in those regions where ozone ridges tend to persist on the mean maps. The annual variation in the Southern Hemisphere seems to be quite similar except that it is about half of that found in the Northern Hemisphere. The data, of course, are quite sparse (there are only eight reporting stations for the IGY-IGC period in the Southern Hemisphere) but the maximum range is probably somewhat south of 70^{o}S and has a value of about 125 milli-atmcm. Although there are not enough data to establish true longitude variations in the annual range it is possible to deduce some asymmetry similar to that for the distribution of total ozone. Analysis of the phase of maximum and minimum ozone shows that in the Northern Hemisphere the maximum occurs in early spring in high and middle latitudes, and shifts with decreasing latitude to late spring and early summer. In the Southern Hemisphere the results are quite erratic. However, it is probable that a pattern similar to that discussed above will develop as more data become available.

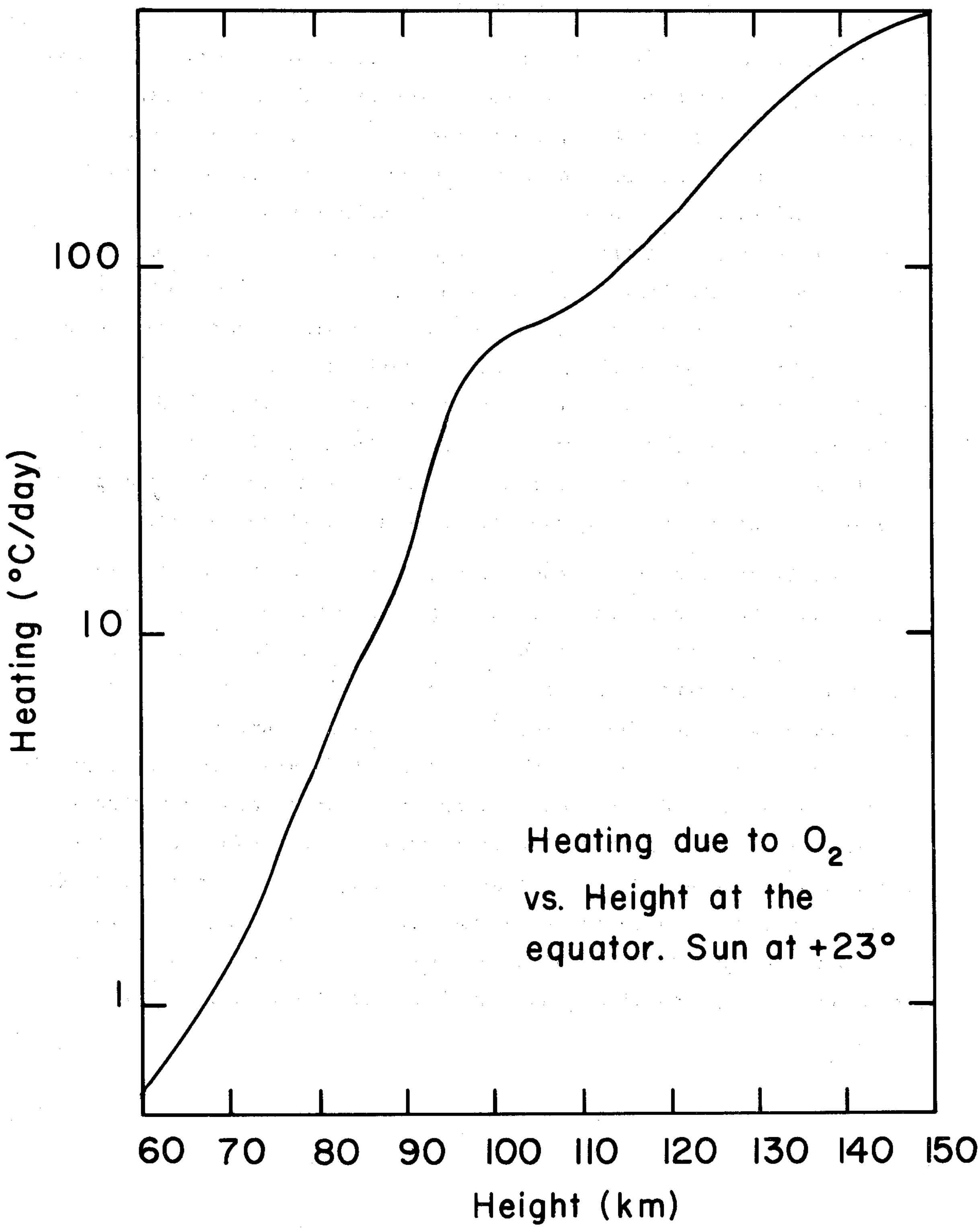
We are now acquiring total ozone data for the additional three-year period 1960-62 and these will be used to supplement the study of the ozone distribution for the IGY-IGC period. Routine analyses of the mean monthly ozone distribution for North America for 1963 are being completed. These will be continued for 1964.

In order to compare the observed and theoretical distributions of ozone, London has undertaken a program to study the photochemical distribution of ozone for both equilibrium and non-equilibrium conditions (i.e. steady state and time dependent). These studies have been made to include hydrogen in the photochemistry. The photochemical equilibrium studies have made use of the most recent data of the solar ultraviolet spectrum and the absorption cross sections for molecular oxygen and ozone. In addition, use was made of the new results of laboratory measurements of the various recombination processes which enter the photochemical reactions. New equilibrium distributions have been calculated and these show, particularly in the mesosphere, great sensitivity to some of the reaction constants used. Of special concern is the tendency for the results to show an increased ozone mixing ratio with height through the mesosphere. There are two possible reasons for this result. First is the neglect in the original equations of the destructive reaction of H or OH with ozone. Since the recombination rate coefficient for the $H + O_3$ reaction is three orders of magnitude larger than the $O + O_3$ reaction, it seems important to include the former in the general ozone budget equations despite the relatively low concentrations of hydrogen in the mesosphere. Also, at heights of about 60-90 km there are sufficient diurnal variations of the photochemical ozone amounts so that the equilibrium value is no longer representative. Photochemical calculations are at present under way: (a) to include the effects of H and OH on the equilibrium concentration, and (b) to study the importance of the non-equilibrium distributions in the mesosphere. When these calculations are completed, the long-term (seasonal) non-equilibrium distributions for the stratosphere will be calculated. It is hoped that combination of these theoretical calculations with the observed vertical distribution (up to about 30 km) will give a reasonable cross section of the ozone distribution for the atmosphere up to about 80 km.

London has extended his study of the energetics of the stratosphere and mesosphere discussed in the last annual report to include the lower thermosphere. The chief thermal energy source for this atmospheric region is the absorption of solar-ultraviolet in the Schumann-Runge continuum by molecular oxygen in the region 80-150 km. Since the vertical distribution of molecular oxygen is, in this layer, reasonably well known, the computation of heating due to absorption of solar energy can be made in a relatively straightforward manner. He assumed that the energy absorbed appeared as thermal energy of the air and was not used to store chemical energy through dissociation (i.e. the time constant for molecular oxygen is long compared to one day). The results shown in the figure on the following page, indicate a heating rate of about $0.5^{\circ}C$/day at 60 km increasing exponentially with height to about $50^{\circ}C$/day at 95 km and then increasing somewhat more slowly to about $500^{\circ}C$/day at 150 km. It is probable that the net 24-hr. temperature change at these levels is relatively small. Thus there must be a net heat flux divergence sufficiently large to offset the heating due to absorption by molecular oxygen. This could be accomplished by thermal emission in the upper mesosphere and lower stratosphere and/or possibly conduction at higher levels. The radiative heat loss presumably would result from infrared divergence due to CO, OH, or O. London plans to investigate the atmospheric energy budget at these levels.

The Stratosphere

Julian continued his work on statistical relationships between tropospheric and stratospheric temperatures and pressures. Among the studies in progress was a zonal harmonic analysis of pressure-height and temperature on monthly-mean charts from 850 mb (approx. 1.5 km) to 25 mb (approx. 25 km). The results depict the structure of the largest scale atmospheric waves (wavelength of the order of the radius of earth) in terms of parameters in wave number space. Theoretical studies of atmospheric structure have been made utilizing zonal harmonic analysis with the wave number parameters as dependent variables, and it thus behooves us to examine the structure of the actual atmosphere to test these theories. A particularly crucial test comes when the troposphere and stratosphere are examined together, since the theoretical studies are concerned with only the former, and the


Heating (°C/day)
100
10
1
60 70 80 90 100 110 120 130 140 150
Height (km)
Heating due to O_2
vs. Height at the
equator. Sun at +23°

observed seasonal variation in the stratosphere of large-scale features (such as zonal wind velocity) utilized as independent parameters in the theories becomes particularly relevant.

Julian also calculated a series of empirical orthogonal functions of pressure, temperature, and a combination of both, for statistical representation of the vertical distribution (1.5-25 km) of these quantities. Such functions indicate the manner in which atmospheric dynamical models can be parameterized for optimum (in the sense of least squares) representation of the vertical structure of the atmosphere. The results indicated that some 60 per cent of the variance in space and in time can be accounted for by a single parameter, thus indicating the extent to which a single degree-of-freedom in the vertical is appropriate. Virtually all (about 90 per cent) of the variability can be accounted for by three such orthogonal functions giving a quantitative basis to the qualitative impression that the atmosphere possesses a high degree of organization in its vertical dimension.

A fairly comprehensive study of tropospheric circulation before, during, and after the sudden stratospheric warming phenomena was made. Such a study, unanticipated at the time of last year's report, was spurred by the occurrence in January-February, 1963 of such a stratospheric warming. With the "sample" of such well-documented events thus reaching four, it was thought advisable to compare the tropospheric circulation associated with the stratospheric event, and to contrast these circulations with four winters in which a stratospheric sudden warming was not observed. Such a study resulting in clear-cut circulation differences would indicate the necessity of coupling the stratosphere and troposphere in theoretical studies of the cause(s) of the warming phenomena, and might possibly indicate the nature of the coupling.

Theoretical Studies

Magnetohydrodynamics (MHD)

The virial theorem investigations by Meyer have been continued with limited success. The usefulness of the generalized form is limited by the complication of the integrals. There seems to be no farther reaching consequence of this form above the already known special cases. A still-promising application is that to stability and oscillation investigations. The available function may there be tailored to the individual situation in the same way the tensor virial form has been used to approximate modes of stellar oscillations better than the scalar theorem does.

The question of instabilities in force-free magnetic fields is of interest with respect to solar atmospheric fields in general and the flare phenomenon in particular. One of the difficulties in the suggestion that magnetic energy is suddenly released in a flare is the short time scale of the event, which is inconsistent with the general gradients and the conductivity assumed in these regions. In this respect the possibility of purely hydromagnetic instabilities as compared to those which only occur with finite conductivity seems not to have been fully explored. Such instabilities could lead to sharp gradients in short time scales corresponding to travel times of Alfven waves. One of the most interesting instabilities of this kind is the kink, or rubberband, instability which can develop by the twisting of a force-free flux tube. The amount of twisting needed apparently could be supplied by penumbral convection rolls as observed by Robert Danielson, of Princeton University. This investigation is still in progress. Closely connected to these instabilities is the "buoyant" uprising of a twisted tube of force. In both these cases the surrounding field is important and makes the investigated types of motion possible. This second case apparently depicts the slowly rising arches sometimes observed in H-alpha.

Skumanich, Meyer and Ellis are considering a numerical two-dimensional MHD calculation using a single fluid approach to study the effect of a magnetic field on motions in a solar-like atmosphere. Two problems are under consideration: (a) field focusing of motions induced by pressure fluctuations and spicule formation and (b) excitation of standing internal gravity waves by lateral MHD shocks (from flares). An extant IBM 704 code developed by our colleagues at Los Alamos will be rewritten for the CDC 3600.

Non-Uniform Gases

Burnett has continued the revision of Chapman and Cowling's *The Mathematical Theory of Non-Uniform Gases*, and considerable progress has been made. Many of the chapters which do not need to be completely rewritten are now approaching their final form, and two new chapters are well advanced. Burnett has devoted considerable time to an attempt to develop a treatment of non-uniform dense gases; this is still in a preliminary stage, but has some promise, and it will be continued.

Thermal Convection

Skumanich has continued, on a reduced scale, last year's studies of problems in thermal convection. The applicability of the Boussinesq approximation to stellar atmospheres remains under study with no further results available at this time.

The departure of Emmanuel in the early part of the year has postponed further study of the applicability of an extremum entropy-generation principle to turbulent thermal convection.

Intermediate Main Sequence Stars

In an effort to obviate difficulties associated with starting values, extended series expansions were obtained by Skumanich for the equilibrium equations governing the inner (core) structure of chemically homogeneous stars (masses between 1.0 and 2.5 solar masses). These expansions replaced the previous ones used in the IBM 1620 code of the equilibrium equations. The code has been debugged and test integrations are now in progress.

The task of deriving numerical procedures for integration of the stellar equilibrium equations (with a high speed CDC 3600 computer) has been begun with Ellis who has recently joined the laboratory. It appears that the so-called "Henyey method" (which is currently in use) is based on relaxation methods for solving differential equations. These general methods are currently under study.

Stellar Populations

It has been found that stars can be separated into different age groups or populations either by their extreme high velocity (relative to the sun) or by peculiarities in their spectra (a deficiency of metals). These two parameters appear to be correlated, with the higher velocity stars being metal poor and older than normal stars.

The sun, on the basis of spectral appearance (based on observations of the reflected light of the minor planet), has been assigned by A. N. Vyssotsky and Skumanich to an intermediate age group identified as "weak line" stars. On the other hand, recent photometric observations (by S. van de Bergh, University of Toronto) of a discontinuity in the continuous spectrum at 4000A for G and K stars, and its correlation with ultraviolet color excess or deficiency (metal excess or dip) appears to place the sun in the "strong-line" or young group of stars. In order to resolve this discrepancy, the photometric properties of the "weak line" vs. "strong line" stars are under study by Few and Skumanich. Both the ultraviolet color excess and continuum discontinuity will be considered. Most of the photometric data is already available. Further, the nature of the unknown source of opacity which produces in the sun a 0.5 magnitude (about 50 per cent) jump at 4000A will also be studied. It is planned to obtain center-to-limb variation of this jump in the sun either at Climax or Sacramento Peak depending on the optimum spectral resolution necessary.

Recently a third parameter, the intensity of the emission core within the Ca^+ H and K lines (which is associated with chromospheric activity), has been reported in the literature to be correlated with stellar age.

The question of the correlation of this parameter with stellar kinematics is unanswered. Skumanich is studying the possibility of observing this parameter for the 8th to 11th magnitude to stars whose kinematic properties were studied earlier by Vyssotsky and Skumanich. The question of a similar program for the brighter stars (e.g. Nancy Roman's list of "strong line" stars) is also being looked into.

Solar Data Reporting

The collection and reporting of solar data remained under the supervision of Trotter, assisted by LaVelle. Data were received directly from the Climax station of the High Altitude Observatory, from the Sacramento Peak Observatory, from the radio spectrograph of the High Altitude Observatory, and from the radio heliograph of the Stanford Radio Astronomy Institute. In addition, data reported from other stations around the world were received through the cooperation of the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards in Boulder.

Reporting of data continued on a daily, weekly, and monthly basis. The daily reporting was largely routine messages of observations made at Climax and Sacramento Peak to the North Atlantic Radio Warning Service in Fort Belvoir and to CRPL. In addition, daily preliminary coronal measurements made at the Climax and Sacramento Peak stations continued to be used by K. O. Kiepenheuer in the preparation of daily maps of solar activity by the Fraunhofer Institute in Germany. Because of the quiet condition of the sun during the year only a few flare messages were sent to interested research groups.

The "Preliminary Report of Solar Activity," prepared every Friday, continues to be the principal fast summary of solar phenomena. It is a selected compilation of all solar data that are available from some thirty stations for the preceding seven days. Phenomena include sunspots, plages, flares, prominences, coronal emission, radio emission, auroras, geomagnetic indices and storms, ionospheric disturbances, and polar cap absorption. In the near future we expect to be able to include measures from our Koronameter now located on Mt. Haleakala, Maui, Hawaii. We are striving to add other relevant information that we can be sure of receiving regularly. As of the end of 1963, the reports were being distributed to 350 persons and institutions.

Monthly provisional coronal indices and quarterly coronal indices for publication in the CRPL "Solar-Geophysical Data" Part B, continued to be prepared. At the end of the year Integrated Indices of the Solar Corona for 1963 are under preparation.

The IGY World Data Center A: Solar Activity, is still a function of the High Altitude Observatory. Data come in monthly from some fifty observing stations, and are available to any interested person and for international exchange. We furnish flare data and flare patrol hours to the CRPL for publication in "Solar-Geophysical Data" Part B. In addition, the Data Center has published three reports during the year. These were distributed to about three hundred persons and institutions.

At the present time the Center has arranged to publish the McMath-Hulbert Observatory Working List of Flares and Daily Flare Index for 1962 and a list of sudden ionospheric disturbances for IGY-IGC to be prepared by the Sun-Earth group of the CRPL. It will also publish the Intermediate Report of Prominence Activity for 1963, which LaVelle is currently preparing.

We also prepared sections of the Eleventh and Twelfth 6-Monthly Catalogue of Data for the IGY World Data Center A: Solar Activity, for inclusion in a publication by the U. S. Coordination Office.

The routine observations of coronal red and green line intensities are reduced in two different ways. The green line spectra recorded at Climax are reduced on a rapid time scale by the Climax staff. The technique, developed by James and Hansen, involves projection of the original spectrogram and a measurement of the light falling on the screen with a photoelectric photometer. We have demonstrated that these measurements are highly correlated with the much slower method of scanning the films in a microdensitometer and integrating under the output deflecting curve of the line. Other coronal observations -- Climax red line and all Sacramento Peak -- are measured in Boulder by Tanton and Ringstad with the microdensitometer.

Instruments

Reflecting Coronagraph

During 1963, Zirin and Newkirk carried on a very preliminary investigation of the feasibility of a reflecting coronagraph. Such a coronagraph would have the distinct advantage that it is completely achromatic and all wavelengths would fall on the slit of an analyzing spectrograph at the same focus with the same scale. This is to be contrasted with the situation with the ordinary coronagraph in which the chromatic aberration allows only a small band of wavelengths to be in focus on the slit simultaneously. Even the vast improvement brought about by the Mangin optical system employed in our 16-in. coronagraph is made with the occulting being performed in a chromatic image.

Liberty Mirror Company has been able to produce aluminum surfaces of extremely fine quality with very low scattered light levels. Tests of a small coronagraph mirror coated by Liberty Mirror Co. showed the radiance of the light scattered by such a mirror to be approximately 1.3×10^{-5} the brightness of the mean solar disk. Such a scattered light level is not much worse than that encountered in an ordinary Lyot coronagraph and is about the same as the best skies at Climax.

Presently, the reflecting coronagraph is still only a laboratory curiosity. It remains to be seen whether the mirror surface will maintain the low scattered light level after exposure to air, dust, and the necessary cleanings. Also, the measurements made in the laboratory averaged the scattered light level from something like two minutes of arc above the solar limb to about eight minutes of arc above the solar limb. A fairer test of the reflecting coronagraph would be to use it as a practical instrument in which the slit of the spectrograph were set only a few seconds to a minute above the solar limb.

16-inch Coronagraph

The coronagraph was essentially finished last year. However, some accessory work remained, and has been partly finished during 1963. A unit was installed to move filtered air through the telescope; but it is not yet operational because the seal around the Coude region is not finished. A remotely-operated dust cover has been installed on the dust tube ahead of the objective, and the new remotely-controlled guider head is in operation.

Spectrograph

The image rotator is complete and ready for installation at Climax. All optical elements for the spectrograph are finished except the collimator, which should be done at any time. Two gratings have been ordered, one being a 10-in. Harrison replica that is reported to be of unusually good quality. The mechanical structure is nearly complete except for the slit and H-alpha viewing system, and the long film-transport unit.

No design changes have been made during the year, except in some details. The work has consisted of steady development of plans that already were essentially complete. In preparation for the spectrograph, the room that will house it at Climax has had a new heating system installed and has been completely re-insulated. This will provide clean, filtered air at a controlled temperature with a minimum of temperature gradient across the room.

Other Instruments

The Koronameter was modified during the first part of the year. The major modifications centered around changes in the recording method. The polarized component is now recorded on a polar recorder (Leeds and Northrup) whose chart position is servo-controlled by the scan position of the Koronameter. A two-channel Sanborn strip chart recorder records sky brightness and polarization, as a function of time, with event marker pens being used to keep track of scan angle. Most of this electronics work was carried out by Garcia.

Solar magnetograph construction has continued throughout the year with Hultquist and Green devoting major portions of their time to it.

The CORONASCOPE II equipment took the major part of the shop's effort in the latter part of the year. We misjudged the completion time rather badly, so our testing of the guider took place in the winter, rather than in the early fall as we had hoped. We were favored with an unusually mild winter, but the testing of the gondola on the boom was made difficult by wind, short days, and cold weather.

The Radio Astronomy project continued on a routine basis with Kuhn taking over management. Operation was routine on 8, 18 and 36 Mc/s with two-element interferometers. The radio spectrograph also continued in routine operation. Our terrestrial magnetometer failed due to overheating in July, and has been out of operation most of the time since then.

Hultquist went to Rome in early 1963 to install an indirect flare detector (IFD) there. They had severe weather for that region during his stay, but the installation was completed, and is yielding good records. The Hawaii IFD has been moved to Haleakala and still needs some work. The Manila unit still suffers from interference of some sort, but is yielding useful results.

Climax

Solar activity has dropped off strikingly this past year as the sun is approaching sunspot minimum. There were only two periods of any activity at all -- one in April and May, and another in September and October -- and neither one of these produced a large amount of sustained active regions. The first sunspot of the new cycle appeared in the fall, and minimum cannot now be far away. The coronal sky time for the whole year was 17 per cent of the available daylight hours, or about 659 hours.

The 5-in. coronagraph continued as in the past as the workhorse research instrument for the station. The Babcock grating was re-installed early in the year in place of the 600-line Bausch and Lomb grating. This gave greater dispersion with some loss in speed. The main purpose of the change was to benefit the image tube, but we have found that the Babcock is very useful on a number of other programs also.

Several new programs were set up. The K and H program to observe the K and H emission lines of calcium, barium, and strontium in the same prominence was begun for Tandberg-Hanssen. A number of good sets have been obtained, although the program is hampered by the lack of dense prominences on the sun. Two programs for Billings were started that involved obtaining coronal line spectra from which very accurate Doppler shift determinations could be made. One involved observing the red line with an artificial neon source line imposed very near by, and the other was to observe the green line at one height above the limb for a long period of time. We are also investigating disk structure in 3888A and 3889A, the appearance of D_3 on the disk just inside the limb, and the occurrence of D_3 high above the limb in coronal regions.

Nearly all of the observing programs used in previous years continued, such as iron series coronal observations, long prominence, spicules in many wavelengths (in connection with this program several sets of very excellent H and K calcium spicules were obtained), active regions -- both limb and disk, routine surveys, and many others.

Once again a complete set of special observations was made surrounding the natural eclipse on July 20. Frequent red and green surveys, H-alpha surveys of the limb, and detailed visual observations were made for many days on either side of July 20. This was to provide support information for the eclipse expeditions in the field.

The scatter of the two lenses used as objectives in the 5-in. coronagraph was measured. The singlet was found to scatter about 8×10^{-6}, and the triplet about twice that amount. It was discovered that the main contributor to scatter was not the minute sleeks and smudges on the lens, but rather the particles of dust that accumulate between cleanings. The triplet lens elements separated early in the year, were re-cemented by Rush and James, and again separated in the fall. Another cementing job is planned.

Most of the electronics for the small dome have been moved downstairs to the electronics room built for the purpose. This has aided the electronics operation and maintenance considerably. A new 45-micron slit was constructed by the shop. It has parallel jaws instead of the concentric jaws that the old slit has. This will make reduction of the spectra easier and more accurate. In line with the extra time now available for testing because of low activity, a new spectrograph focus test was run and carefully analyzed and a new focus scale derived. Quite a bit of optical alignment has been done, and more is planned for in the near future.

No major changes or modifications were made in the flare patrol or its operation during the year. The suppressor plate froze and separated again in the very cold weather of January, and it has remained out of use since that time. A rather thorough optical realignment of the instrument took place in August.

During the spring (May and June) a systematic search was made for the West Ford Needles with the coronameter. The results were negative, and this could be for a number of reasons: we may not have been looking at the right place in the sky; the instrument may not have been sensitive enough; or the needles just may not have been detectable in this way.

Two steps were taken to try in some small way to improve the seeing around the domes. Both domes were painted with Pioneer white paint (a titanium dioxide paint) this fall. This particular brand of paint has been found to be very good in lowering the heating of the metal domes. The other project was to plant grass and bushes from the surrounding hillsides in the area to the south of the big dome. Last year a number of Aspen trees were planted around the small dome. It will be hard to determine if these efforts really improve seeing conditions, but they certainly cannot be a step in the wrong direction.

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Personnel

Director

John W. Firor

Scientific Staff

Athay, R. Grant (On leave from September 5, 1963)
Billings, Donald E. (Combined Appointment with the University of Colorado)
Chapman, Sydney (Combined Appointment with the University of Alaska)
Eddy, John A.
Hansen, Richard T.
Haurwitz, Bernhard (Combined Appointment with the University of Colorado)
Heynekamp, Christiaan E.
House, Lewis L.
2 Hyder, Charles (From October 16, 1963)
Julian, Paul R.
London, Julius (Combined Appointment with the University of Colorado)
Matsushita, Sadami
Meyer, Friedrich
Newkirk, Gordon A., Jr.
Rush, Joseph H.
Skumanich, Andrew
Tandberg-Hanssen, Einar A.
Trotter, Dorothy E.
Warwick, James W. (Combined Appointment with the University of Colorado)
Zirin, Harold

Visiting Scientists

Ashour, Attia A. S.
Burnett, David
Godbole, Ramesh V.
5 Kendall, Peter C. (July 16 - December 31, 1962)
Maeda, Hiroshi
RajaRao, K. S.
5 Saito, Kuniji (August 1 - December 26, 1963)
11 Singleton, Donald G. (January 1 - November 30, 1963)

Research Assistants

T Braidwood, Harold T.
T Broomell, Stephen H.
T Bruce, Leslie B.
Canfield, Karen
R Collins, Peter
T Davidson, Lendell W.
R Deirmendjian, Astrik
Fields, L. Jean
R Fisher, Patricia A.
R Fuery, Patrick R.
Garcia, Charles J. (To October 31, 1963)
R Gay, Marjorie E.
R Glasco, Helen P.
T Goff, John E.
T Green, David E.
T Hansen, Dale R.
T Hanson, Robert G.

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T Hull, Howard K.
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T Kuhn, Philip S.
T Lacey, Leon B.
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T Lee, Robert H.
R Lilliequist, Carl G.
Mao, Louise (June 3 - August 12, 1963)
R McKean, Kathryn
½T Minor, Wallace G.
½T Phillip, Charles W.
½T Richard, Earl R.
R Ringstad, Jean
T Southward, Bryan B.
T Tanton, Dallas E.
½T Thomson, Gerald J.
T Travis, Mary C.
T Wendler, Robert F.
R Wightman, D. Adelle
T Wyman, Clyde M.
R Zirin, Mary F.

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Goss, Georgia B., Acting Librarian

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Hulett, Darlene A.
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Workman, Eileen R.

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Avery, Lorne
Bohlin, John David
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Deutschman, William A.
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Fisher, Richard R.
Gordon, Mark
Henze, William
Kreiss, William
Lund, Donald S.
Moore, Carroll (To August 30, 1963)
Rust, David M.
Schoolman, Steven
Switzer, Billy A.
Weinberg, Jerry L. (To September 30, 1963)

Climax Observing Staff

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King, William Dale
Sanchez, Juan F.
Stevenson, Peter R.
Watson, D. Keith, Observer-in-Charge

Research Associates

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Robert F. Howard, Mt. Wilson and Palomar Observatories
John T. Jefferies, Joint Institute for Laboratory Astrophysics
Donald H. Menzel, Harvard College Observatory
Walter Steiger, University of Hawaii, Department of Physics
Richard N. Thomas, Joint Institute for Laboratory Astrophysics

FACILITIES DIVISION

Introduction

In a reorganization during the year, the Facilities and Administration Division of NCAR was separated into two independent divisions, one of which became the Facilities Division. Its mission is to provide technical services to the programs of scientists throughout the scientific community, including those at NCAR.

The active facilities operating within the Facilities Division are the NCAR Scientific Balloon Facility, the Library, and the Machine Shop. Others are in various stages of study and planning: an Aviation Facility, a Micro-Mesometeorology Facility, an Electronics Shop, and a scientific Glass Shop. One which has not passed the most preliminary study stage is an Atmosphere Simulation Chamber.

A separate report for each of the active facilities follows this introduction. They will not be discussed further here. Separate reports on the status of planning for an Aviation Facility and a Micro-Mesometeorology Facility also follow the introduction; however, it is appropriate to discuss a common aspect of the planning for such facilities here.

These latter facilities, like the NCAR Scientific Balloon Facility, are characterized by their usefulness to scientists throughout the country and by the relative magnitude and complexity of the services they can perform. They may be contrasted to facilities such as the Library or the Machine Shop which perform services of a generally less complex nature principally for scientists at NCAR. We have chosen to distinguish the two by calling one an NCAR Facility and the other a Support Facility.

Before any planning can be done for a facility, we must be made aware of the need for the facility. The scientists having a requirement must call it to our attention, or it must be a matter of record in the professional literature. Once recognized, we make a preliminary study to determine whether the requirement appears to be sufficiently general in the scientific community to warrant NCAR support. If we think it is, we attempt to determine the general feasibility of establishing a facility to meet the requirement. When this appears to be real and relatively general, and the means of providing the desired service seem feasible, we present the information to a group of eminent scientists who are qualified by virtue of their education, background, and current interest to advise us on all facets of the problem. The group, consisting of from five to seven scientists drawn from the scientific community outside of NCAR, one technical representative from NCAR, and a secretary from NCAR, is called a Survey Group.

During the past year we have had two active Survey Groups. One, the National Aviation Survey Group, finished its work and issued its final report just at the end of the year. Included here are a summary of that report and our plans for an Aviation Facility. The second group, the National Micro-Mesometeorology Survey Group, is still working, but some of its tentative findings are known and are also included in this section.

Requirements for an electronics shop and a glass shop have been growing rapidly within NCAR, and tentative plans have been made to initiate both types of service within the next one to two years. Since these requirements are internal to NCAR, no survey group has been or will be appointed.

Requirements have been stated both formally in the literature and informally by researchers in the field for a chamber in which such atmospheric parameters as air movement, temperature, pressure, humidity, electric field gradients, etc., can be carefully controlled and in which such atmospheric phenomena as the growth of raindrops may be studied. The chamber must be large enough that the influence of the walls is negligible. A start has been made toward determining the feasibility of building and operating such a chamber at NCAR, but much more must be done before we shall feel justified in appointing a survey group. Work will continue in an effort to determine the feasibility of such a chamber.

Daniel F. Rex
Director

Library

Jack M. McCormick

A library program was initiated early in 1962 to provide the information contained in books, journals, reports and similar research publications that is required by NCAR personnel in their work. As the library developed, its activities included acquiring, organizing, processing, indexing, announcing, circulating and searching of this information.

During the first two years we have been mainly concerned with selecting and ordering the most needed basic journals and books in the atmospheric sciences. By the end of 1963, the library was subscribing to 315 journals and had back-issue files of about 1,800 volumes. There were about 2,800 books in its collections and nearly 2,500 technical reports. All this material is now available to users.

A library bulletin has been issued regularly since July, 1962; it announces newly received material, and is distributed to the NCAR staff. A courier service is maintained to obtain requested publications from the University of Colorado library and from other research libraries in the area. When staff members request them, bibliographies are prepared, and English translations are arranged for needed articles from foreign journals.

The library will continue to develop its collections by a selective but vigorous acquisition program; particular emphasis will be given to expanding its collection of technical reports during the coming year. The most useful documents issued by other major agencies in the atmospheric sciences are being solicited to this end. The library also intends to expand and improve its indexing and announcing services by the use of data processing equipment. The first such experimental announcement bulletins are now being prepared from punched cards, and cumulative author and subject indexes are planned for by the end of this summer. It is also hoped that internal library procedures may be automated within the coming year, for increased efficiency and faster service to the library users.

Machine Shop

Marvin C. Hewett

Organization and Personnel

The organization of a new machine shop began with Hewett's arrival in March, 1962. Between March and May, 1962, when the first building at 30th Street was completed, basic machines and equipment were selected, procured, and stored. In October, 1962, the shop became operational. By November the work load had become sufficient to warrant a shop assistant and an additional machinist. The work load increased continually during 1963, and the staff grew to 12 by the end of the year.

The shop staff and all of NCAR was saddened and grieved by the illness and death on December 24, of Edward Henneke, the first machinist added in November, 1962. Despite the short time he was with us, examples of his skilled craftsmanship are found in several of the laboratories.

Purpose and Goals

The purpose of this support facility is to design and fabricate whatever specialized mechanical equipment is required for the scientific programs at NCAR. This requires broad, well developed skills in both design and fabrication, and a broad spectrum of shop equipment. The shop will continue to develop in all these aspects, within the limits imposed by space and budget, to meet the requirements placed upon it.

Summary of Activities

The Machine Shop, during 1963, turned out over one hundred completed projects ranging in cost, in terms of time and material, from \$50 to \$7,400. This represents the work of an average of 3.3 machinists and a total cost of approximately \$31,000. No record was kept of minor jobs valued at \$50 or less; these were charged to Shop overhead.

The first year of full scale operation was somewhat hampered by lack of space. Working space has been cramped, and space has not been available to store adequate supplies of stock and hardware. With the rapid increase of work load and inability of the shop to expand proportionately, services have not always been as prompt as desired. Plans have been made for additional space adjacent to present shop space, and a second expansion will occur when permanent quarters are ready on Table Mountain.

NCAR Scientific Balloon Facility

Vincent E. Lally

The NCAR Scientific Balloon Facility is now operational. A major building program has been completed at Palestine, Texas, although certain key structures must be deferred for another year. Development programs in materials and launch techniques have been formulated, and await only the funds for implementation. Plans are being developed for the establishment of a winter launch site at Page, Arizona.

Palestine Scientific Balloon Flight Station

The Scientific Balloon Flight Station has been in full-scale operation since August 18, 1963. Twenty-five flights were conducted during 1963 for scientific research groups that included M.I.T., the Dudley Observatory, Case Institute of Technology, University of Minnesota, U.S. Army Ballistic Research Laboratory, Air Force Cambridge Research Laboratories, University of Rochester, NASA, Southwest Research Institute, and University of California. In December, the Stratoscope II telescope was flown by Dr. Martin Schwarzschild of Princeton University, on a most successful flight from Palestine.

With a staff of twelve, Raven Industries, Inc. provides for maintenance and operation of the facility, under contract to NCAR, while NCAR maintains a resident staff of three. Also under contract, the U.S. Weather Bureau operates a weather station for balloon launch and trajectory forecasts.

Physical facilities now include a main laboratory and operations building that contains office space, shop areas, radiosonde facility, communication center, photo lab, and staging area. A new warehousing and staging building has been completed and is fully occupied; housed in it is a 27-cu-ft simulation chamber for instrument testing. For balloon tracking, three- and ten-centimeter radars are in operation.

A shelter building in which large balloons may be inflated is a critical item in providing reliable ballooning. Such a building, termed a Clam Shelter by its designers at NCAR because of the way it opens to permit exit of an inflated balloon, has been designed but not yet built because of fund restrictions. A new launch vehicle, capable of handling all projected payloads, has also been designed and will be in operation by May, 1964.

Glen Canyon Scientific Balloon Flight Station

An agreement for NCAR use of a site at the base of the Glen Canyon Dam has been made with the Bureau of Reclamation. Final construction plans await the results of an extensive NCAR survey of the wind regime in the Canyon and surrounding area. The survey will be completed in April, and initial construction of launch facilities will begin in fiscal year 1965.

Major Flight Support Programs

Initial flight tests have been made for the Polariscope program of Dr. A. M. J. Gehrels and Dr. Gerard Kuiper (U. of Arizona), and Dr. Zdenek Sekera (UCLA). Telescope flights will be conducted in April, 1964.

Flight tests for Newkirk's Coronascope II system have failed on ascent, and a reinforced balloon system has been procured for the first telescope flight scheduled for late February, 1964.

Development Programs

The NCAR Standard Balloon Telemetry and Command System has successfully completed bench tests. It will be test flown in the spring of 1964 and made available to the scientific community by the summer of 1964.

Major programs are required in the development of improved, moderate-cost balloon fabrics and in improved launch techniques for heavy-load systems. Work will be concentrated on these projects during 1964.

Fifteen flights of small superpressure balloons were conducted in 1963. These balloons are believed to be suitable as vehicles for obtaining global atmospheric measurements. Those tested flew at their design altitudes for periods of up to five days with about 80 per cent reliability. It is planned to fly a group of similar balloons from Japan in the spring of 1964 on trajectories across the Pacific, the U.S.A., and terminating in the Atlantic. These tests will verify the balloon and electronic capabilities of the system.

Aviation Facility Development Study

John W. Hinkelman, Jr.

Introduction

A vital part of the NCAR mission is to make available to university and NCAR scientists the facilities that are beyond the reach of individual research groups. One of the most obvious and typical of such facilities is an aviation facility, now in its formative stage.

A National Aircraft Facility Survey Group was appointed in July, 1963, to study and report upon the scientific community's requirements for aviation services. In their final report of December, 1963, the Survey Group strongly recommended the establishment of a scientific aviation facility at NCAR. The Survey Group was composed of scientists from outside of NCAR, experienced in the uses of aircraft for atmospheric research, assisted by members of the NCAR staff. Dr. Robert A. Ragotzkie of the University of Wisconsin served as Chairman.

The program recommended by the Survey Group reflects the importance of aviation services to the atmospheric scientist. It is one which NCAR believes can be accomplished within its over-all long-range goals without major changes.

Facility Requirements and Mission

The requirement for establishing the Aviation Facility stems from the following factors:

1. Aircraft platforms are invaluable for carrying out scientific measurements of atmospheric variables for research purposes, and for conducting experiments aimed at furthering our understanding of the atmosphere. There is a definite research need to observe the three-dimensional structure of the atmosphere with much higher resolution than that provided by the present observational network both at ground level and at great altitudes. Aircraft, properly instrumented, are capable of providing very high resolution in the troposphere and lower stratosphere at relatively low cost. In addition, aircraft observational platforms are useful for indirect measurement of upper atmospheric parameters relating to the ionosphere and above.

2. No single group is responsible for assisting the scientific community with the common problems that arise in research aircraft operation -- air space use, aircraft bailment, space availability on aircraft in use, frequency allocation, observer training, and so forth.

3. There is no focal point for development of aircraft research instrumentation (sensors, recorders, storage) which is of common interest to the scientific community that is engaged in atmospheric research. Instrumentation currently available is, in general, not adequate to obtain the research data required.

4. Adequate and economical platforms are generally not available when and where required to carry out necessary basic research programs.

The primary requirements, therefore, include assistance and service, the development of airborne instrumentation, recording and data processing systems that sense and convert analog quantities into the form needed by research scientists for theoretical studies, and the provision of aircraft platforms.

The mission of the Aviation Facility is to:

1. Coordinate within the scientific community (universities, other research agencies, and NCAR) atmospheric research projects that involve the use of aircraft as instrument platforms.
2. Provide services to atmospheric research projects in the scientific community that can best be handled by a centralized source.
3. Conduct research and development of instrumentation, recording and data reduction techniques, and other devices in which members of the scientific community requiring aircraft platforms have common interest.
4. Provide facilities instrumentation, aircraft flight support, and data reduction, initially to internal NCAR atmospheric research projects requiring aircraft platforms, and eventually, as the capability develops, to the university and other research groups.

Technical Program

The technical program of the Aviation Facility is aimed at achieving the capability for high quality scientific aviation operations in the shortest possible time. To do this in a systematic and economical manner requires that a certain sequence of steps be followed. The first step--determining operational requirements--has already been completed. From these requirements, the envelope of operational flight conditions and data sensing, recording, and processing needs has been defined. Initially the flight requirements of NCAR dictate the type of aircraft to be procured and include two light twin-engine supercharged aircraft of the Beechcraft Queen Air category through fiscal year 1965, and a light twin-jet aircraft early in fiscal year 1966. These aircraft will be available to assist in other than NCAR programs as determined by a Scientific Advisory Panel.

The envelope of data requirements has determined the instrumentation which is common to most flights and has led to specifications of standardized bench-mark instrumentation systems. The basic instrumentation system will be designed to allow installation in any of the aircraft. Coordination services and one Queen Air aircraft will be functioning by April, 1964, and the basic instrumentation system should be in operational status by July, 1965. Within twenty-four months the facility should be operating with a fully established organization in a routine manner.

The NCAR research activities for which aviation facility support is presently required include: 1. cloud electrification and precipitation program; 2. cloud nuclei and thunderstorm program; 3. vertical ozone distribution program; and 4. isotope geo-physics program. The atmospheric chemistry, shock wave, and effects on particulates programs and HAO's solar eclipse and ionospheric studies will be supported as requirements arise.

Program Implementation

An instrumentation engineer and a flight program engineer will join the Aviation Facility staff early in 1964. An electronics engineer, two project engineers and a meteorologist to coordinate services to using groups, will also join the Facility staff in the near future. Staffing will be gradually increased to handle the projects and associated development as well as to activate actual test operations, and to perform pre- and post-flight calibration and data reduction functions.

Publications

Details of the Survey Group Report, including an analysis of aircraft needs and the plan for the Aviation Facility are contained in NCAR Technical Note 64-1, "An Aviation Facility for the Atmospheric Sciences."

Micro-Mesometeorology Facility Development Study

William S. Lanterman, Jr.

In August, 1963 a National Micro-Mesometeorology Facility Survey Group was appointed by NCAR. This Survey Group, chaired by Dr. Hans A. Panofsky, of Pennsylvania State University, consists of seven scientists chosen for their competence in the field of either micro- or mesometeorology. These members serve as representatives of the national scientific community, rather than as representatives of the agency or institution of which they may be a part. They have been asked to analyze the national need for facilities whose primary purpose is support of basic research in micro- and mesometeorology. The group will submit recommendations on the establishment of facilities to meet any needs that are found to exist.

On the basis of discussions during three meetings of the Survey Group, a list has been prepared of those problem areas in which existing facilities are deficient and in which progress is deemed essential. These are:

1.) Relation between free-air variables and boundary layer variables.
2.) Studies of transport and diffusion of gases and particulates.
3.) Propagation of waves through the atmosphere.
4.) Effect of change of terrain on fluxes and profiles.
5.) Short-range forecasting.
6.) Study of severe storms.
7.) Cloud physics.
8.) Satellite support.
9.) Transfer of mass, energy, and momentum between atmospheric phenomena of various scales.
10.) Specification of optimum spacing for meteorological measurements.
11.) Study of convective dynamics.
12.) Quasi-horizontal eddies above the planetary boundary layer.
13.) Exploratory description of meso-scale circulations.
14.) Mesometeorological test areas.

To support basic research in these problem areas, equipment to obtain the necessary data must be procured or developed. In examining the varied observational requirements, it becomes apparent that there are several immediate, unfulfilled needs.

Profiles of half-hour averages of wind, temperature and moisture at many levels up to 5,000 ft are required. These boundary layer profiles are needed in almost every problem area, but equipment to obtain the data is not presently available.

Greater rawinsonde coverage is needed to supplement present coverage in several problem areas. Even the present investigation of severe storms lacks adequate rawinsonde support.

Radar observations, although available at many sites, are needed at additional locations for use in connection with such problem areas as cloud physics, satellite support, convection dynamics, and eddies above the planetary boundary layer.

Only after NCAR receives the final report from the Survey Group can detailed plans be formulated concerning its possible role in providing facility support in the fields of micro- and mesometeorology. However, internal NCAR requirements make it imperative that we develop limited radar and rawinsonde facilities. This, coupled with the present program development of sensors, data processing equipment, telemetry, etc., will provide a base upon which to implement any recommendations made by the Survey Group.

LABORATORY OF ATMOSPHERIC SCIENCES

Introduction

During 1963 the LAS scientific programs mentioned in the Annual Report for 1962 have made continued progress both scientifically and in the gradual build-up of personnel and laboratory equipment. Three new programs were started this year with the addition to the LAS staff of Drs. Richard D. Cadle, Yoshinari Nakagawa, and Chester Newton. Dr. Nakagawa, who joined NCAR following a year with the Joint Institute for Laboratory Astrophysics in Boulder, is working in the area of plasma physics; Dr. Cadle, from the Stanford Research Institute, is starting a program in photochemistry; and Dr. Newton, formerly with the Severe Storms Project of the U. S. Weather Bureau at Kansas City, is building a synoptic meteorology group. All of the new and continuing programs of LAS are described in detail in the reports which follow this introduction.

NCAR continues to stress interest in a broad range of disciplines within the atmospheric sciences. The general policy remains as before: to bring together productive and potentially productive and original scientists, preferably with interests in more than one branch of atmospheric science, and to let their own interests and enthusiasms provide the impetus for the work in their programs. Therefore, even with the addition of the three new programs, the research program of LAS as a whole is not a completely balanced one. This imbalance is in part due to the fact that LAS has not as yet reached full strength. Moreover, since an integral part of the scientific staff is and will be made up of visitors from the U.S. and abroad, it will be possible to focus interest and effort on fields in which NCAR's permanent staff is now deficient.

As in past years, LAS has benefited greatly from a strong program of visiting scientists. The stimulation of interdisciplinary discussion and exchange of ideas, plus two separate series of seminars in the summer of 1963, has proved to be beneficial both to visitors and to NCAR's permanent staff members. During 1963 the primary effort to bring visitors to NCAR was focused on the three months of summer when many scientists are free from university post and laboratory commitments. Forty-eight scientific visitors spent from two weeks to three months in Boulder during the summer of 1963, and many of these expressed an interest in returning for the summer of 1964. On the whole, visitors spent their time at NCAR on their own research combined with discussion among colleagues. However, a few visitors each year come to NCAR to work with the members of one specific program. During the coming year, LAS hopes to encourage more long-term visitors who can plan to spend enough time here to accomplish a significant piece of work.

In connection with the visitors program, a new postdoctoral program has been initiated under the leadership of Dr. Philip D. Thompson. Although still in the first stages of build-up, this program hopes eventually to attract as many as ten postdoctoral appointees. These appointees would spend one or two years at NCAR, during which time they would be expected to attend a series of seminars given by permanent "faculty" members of the group and by NCAR permanent staff members. They would also be free to study all the programs of LAS -- thus building up a definite idea of the problems in many areas of atmospheric research -- and/or to associate themselves with one specific program. At present, the postdoctoral group consists of Dr. Philip D. Thompson, Dr. Bernhard Haurwitz, and Dr. Ragnar Fjørtoft of the Norwegian Meteorological Institute, who will join the group in the summer of 1964. By mid-1964, it is anticipated that this program will be so active as to require full attention from Dr. Thompson, and Dr. W. W. Kellogg will then take over the directorship of LAS.

In keeping with NCAR's role as a national center and meeting place for all branches of the atmospheric sciences, NCAR was the host in late summer of 1963 for the IUGG Symposium on Large-Scale Dynamics in the Atmosphere.

It should be stressed that the reports of the scientific programs which follow were intended primarily for internal use and as a general summing up of the year's activities for the Director of LAS. It is hoped, however, that somewhat wider distribution of these summaries of LAS work in progress may stimulate interest in the atmospheric sciences on the part of students, scientists, and the general public.

Philip D. Thompson
Director

Photochemistry

Richard D. Cadle

Group Members

This program was initiated in July by the arrival of Dr. R. D. Cadle. The first week of October some laboratory space became available. Mr. Frank E. Grahek, a technician, was hired to aid in the construction of necessary apparatus, and laboratory work was started.

Dr. Eric R. Allen, a photochemist with four years of post-doctoral fellowship experience, joined the program on the first of November.

Past Work

During the first few months of the program, Cadle completed two studies which involved analyzing published data in terms of their possible significance to atmospheric processes. One of these studies involved calculating the concentrations of excited (^1D) atomic oxygen in the altitude range 20-240 km.

The estimates for the 100-240 km region were based on calculations of the 6300A line intensity by Brandt while those for the region below 100 km were based on calculations of the rates of photolysis by ultraviolet radiation of O_3. The results suggest that in addition to the strong (50 kR) red day airglow above 100 km, there may be a weaker glow (2 kR) in the 10-100 km region. The results also suggest that the $O(^1D)$ concentrations are sufficiently high that the reaction

$$O(^1D) + N_2 \rightarrow N_2O + h\nu$$

may contribute significantly to the N_2O content of the atmosphere and the reaction

$$O(^1D) + H_2O \rightarrow 2OH$$

may occur at an important rate in the stratosphere. A paper based on this study will be presented at the forthcoming symposium on "Chemical Reactions in the Atmosphere," a meeting organized by the Faraday Society to be held in Edinburgh, Scotland, in April, 1964. This paper will later be published in the "Discussions of the Faraday Society." The other study dealt with chemionization in the earth's atmosphere. It may be defined as the production of primary ions as an integral part of a chemical reaction, and certainly occurs to some extent in the natural atmosphere. Laboratory studies of chemionization reactions have suggested rate constants at least as large as those for fast neutral gas-phase reactions. This fact combined with the available information concerning concentrations and rates of reactions in the atmosphere was used to suggest chemionization reactions which possibly occur at a sufficient rate in the atmosphere to have an appreciable effect on chemical composition and electron concentrations. Calculations based on the available data demonstrated that in the E- and F-region the only reaction which is likely to be important is

$$N(^2P) + O(^3P) \rightarrow NO^+ + e$$

This reaction may also be important in auroras and less important in the D-region. The reaction most likely to be important in the D-region is

$$Na + O + O \rightarrow Na^+ + O_2 + e$$

Reactions between ground-state O_2 and N_2, and very highly excited species produced by cosmic rays or highly energetic electrons may be important in the lower atmosphere and auroras.

A paper based on this study was presented at the national meeting of the American Geophysical Union in Boulder in December. It has been submitted for publication in the Journal of Geophysical Research.

Two experimental studies have been initiated, and equipment is being purchased to commence a third. Of the two experiments already under way, one is designed to study chemical reactions of atomic oxygen that occur in the atmosphere. Reactions between atomic oxygen and methane, sulfur dioxide, ammonia, and hydrogen sulfide will be included. In particular, rate constants and activation energies will be obtained to facilitate the calculations of the rates at which these reactions occur in the atmosphere. The influence of additives such as water vapor and molecular oxygen on the rate constants and the products will be investigated.

Microwave discharge techniques are being used to produce ground state (^3P) atomic oxygen. The local concentrations of atomic oxygen are being determined by a titration technique using nitrogen dioxide and nitric oxide. The reaction with methane is currently being studied. Concentrations of methane before and after reaction as well as those of its reaction products are being determined with the mass spectrometer. It is hoped that the arrival of gas chromatographic equipment currently on order will permit analysis to be carried out in situ and greatly expedite the production of analytical results.

An application has been made to the U.S. Public Health Service for a grant of funds to help support the study of atomic oxygen reactions.

The second laboratory study that has been started involves the determination of the rate constants and activation energy of the reaction of hydrogen sulfide with ozone. This reaction is of interest since it occurs in polluted air. It is also of prime interest since it may contribute to the sulfate particulate layer in the stratosphere that was discovered a few years ago by Junge. Work at present is directed toward finding a satisfactory method for analyzing for ozone in the presence of hydrogen sulfide. Two methods are being explored. One is based on the ozonolysis of dimethoxystilbene (a method previously developed at NCAR by Lodge). The other is based on the very rapid gas-phase reaction of ozone with nitric oxide.

Future work

The third experimental study for which equipment is now being obtained will be a study of the reactions of oxygenated radicals with nitrogen oxides. Of particular importance are the reactions of alkylperoxy radicals with nitric oxide and nitrogen dioxide. The radicals will be produced both photochemically and thermally to distinguish between the reactions of energy-rich and thermally equilibrated radicals. Later studies will include the reactions of alkoxy radicals with the oxides of nitrogen as well as the reactions of methylene radicals with carbon monoxide and nitrogen. The results obtained from these studies should be applicable not only to the mechanisms involved in photochemical "smog" formation, but may also contribute to a better understanding of the processes which may occur in the natural atmosphere, since little is known regarding relative rates, activation energies, or stability of intermediates in the foregoing systems. The following major pieces of equipment have been obtained:

(1) Raytheon microwave power generator
(2) Micro-micro ammeter
(3) Regulated high-voltage supply
(4) Wellsbach ozone generator
(5) High-volume vacuum pump
(6) Thermocouple gage
(7) Varian recorder (G-14)

Atmospheric Optics and Radiation

Jitendra V. Dave

I. Group Members

Name	Position	Date of Joining
Dr. J. V. Dave	Program Scientist	1 Feb. 1962
Mr. I. H. Blifford, Jr.	Research Engineer	1 Feb. 1963
Mr. C. E. Shelden, Jr.	Instrument Engineer	1 Jul. 1963
Mr. P. M. Furukawa	Physical Meteorologist	17 Dec. 1962
Mr. D. F. Kimball	Programmer	1 Aug. 1963
Mr. G. J. Dolan	Technician	3 Jun. 1963
Miss Mary Jo Scharberg	Programmer & Secretary	8 Aug. 1963

From its beginning, the work of this program has been done in cooperation with Prof. Z. Sekera (UCLA), who has been guiding the research work as a visting consultant.

II. Theoretical and Numerical Studies

1. Work has been completed on the problem of the effect of ground reflection on the scattered sky radiation in the presence of ozone absorption. Only primary scattering of the direct solar radiation and of the radiation reflected from the ground was considered. The numerical results for the case of the zenith direction discussed by J. V. Dave and P. Furukawa(VI) show a considerable increase in the intensity of primary scattered radiation due to ground reflection. The effect of ground reflection on the ratio of the intensities of the wavelength pairs used in Umkehr analysis was also discussed in the paper.

2. Numerical computations on the radiation diffusely transmitted by a homogeneous, plane-parallel, non-absorbing molecular atmosphere after undergoing one, two and three scatterings were completed. The results discussed by Dave(VI) clearly bring out the necessity for inclusion of the first three orders of scattering even for an atmosphere of optical thickness of the order of 0.20. It was noticed that the present step-by-step method of evaluating higher orders of scattering in an optically thick atmosphere is not very practical since the number

of scattering processes involved is very large. It was also observed that the anisotropic nature of the scattering molecules should be taken into account for obtaining reliable theoretical results.

3. Attempts to obtain numerical values of X- and Y- functions (of Prof. Chandrasekhar) required in the computations of diffuse relection and transmission of radiation by a Rayleigh atmosphere met with limited success. For optical thickness greater than unity, successively iterated values of X- and Y- functions (for some characteristic functions) converged only up to a few places after the decimal point. Further attempts to make the successive iterated values agree to desired places of accuracy resulted in oscillations whose magnitudes were found to increase with the number of iterations, optical thickness and the nature of the characteristic function. The reasons for this were found in a very recent work of Dr. T. W. Mullikin (The Rand Corporation) who arrived at further constraints necessary to obtain the unique solution. Further work in this direction has been postponed until the work can be completed on another more promising approach described in section (II.4).

4. The problem of radiative transfer in a planetary atmosphere with imperfect scattering was recently solved by Sekera. Dave showed that the successive iteration of the solution of the auxiliary equations derived by Sekera has a definite physical meaning: that of including successively higher orders of scattering. The work was also extended to include the effect of Lambert-type ground reflection on the Stokes parameters of the diffuse radiations. A paper, "On the Physical Meaning of the Successive Iteration of Auxiliary Equations in Radiative Transfer," will be submitted to the editor of the Astrophysical Journal in a couple of months. A clear understanding of the problem has made it possible for the first time to estimate contribution from the higher orders of scattering on the diffuse radiation emerging at any level of an optically thick and/or nonhomogeneous atmosphere.

Detailed numerical studies of the following problems will be carried out in the near future: (a) effect of multiple scattering and of Lambert-type ground reflection on diffuse radiation emerging from a Rayleigh atmosphere of optical thickness up to 10.0, (b) necessity of considering anisotropic nature of molecules in (a), and (c) Stokes parameters of the diffuse ultraviolet radiation (2900-3600A) received at any level in the earth's atmosphere after taking into account multiple scattering and ground reflection.

The numerical studies described in (a) and (b) are to some extent related to the experimental work mentioned in section (III.2); that described in (c) to the experimental work mentioned in section (III.1).

III. Experimental Studies

1. An ultraviolet double monochromator is being constructed for obtaining the vertical distribution of atmospheric ozone from the measurements of the scattered skylight at several wavelengths. In principle the method is capable of giving the ozone distribution from measurements taken over a period of several minutes and, therefore, it can be used to obtain (a) diurnal variations in the ozone distribution over a station, (b) day-to-day variations at several widely spaced stations with the same instrument mounted on an aircraft. The experience so gained can then be used to construct and use a similar satellite-borne instrument for obtaining ozone distribution data on a planetary scale. A regular and reliable series of such observations would be of great value in studies of the problems related to photochemistry and general circulation of the stratosphere.

The paraboloid mirror-grating double monochromator originally designed by our consultant, Dr. W. T. Welford (Imperial College, London), was examined in detail. It was decided to postpone further work on this very complex instrument because of several practical difficulties. Instead, the optical design of a less elaborate, spherical mirror-grating double monochromator (also prepared by Welford) was accepted. He has also given some instructions which will help towards testing of some optical components and the final instrument. The work on the mechanical design and other related aspects of this modified instrument has been started by Shelden, keeping in mind its use aboard a jet aircraft. The necessary optical components, electro-mechanical and electronic accessories are being ordered. It is expected that the actual construction and testing of some components will be started by summer 1964. The instrument is expected to be ready for the ground-based observations by summer 1965.

The relative response of the monochromator within and outside the physical width of the slit was computed using the diffraction theory. For identical entrance and exit slits, the slit-function was found to be triangular, as expected. Due to diffraction, however, the wings were found to reduce considerably the spectral purity of measurements at shorter wavelengths and low sun. This problem as well as some details of both optical designs were presented in a joint paper by Welford and Blifford (V).

A ray-tracing program has been developed by Shelden from which one can obtain the spot diagram of the image of a point source for spherical (or paraboloid) mirror-grating type monochromator. This program uses the actual grating equation instead of the plane-mirror approximation commonly used. The program will be extended to include computations of the instrument transfer function for comparison and checking with laboratory results. This numerical study will help in design modifications without undergoing some costly and time-consuming experimental testing.

2. Several characteristic parameters of the atmospheric aerosol can be determined from the measurements of the direct solar radiation and of the scattered sky radiation during day and twilight. In order to obtain meteorologically acceptable measurements in places unaffected by local pollution, a clear understanding of the process of radiative transfer [section (II.4)], as well as considerable improvements in the existing techniques of radiation measurements are absolutely essential. Significant contribution from higher orders of scattering and strong screening effects of the low-level haze make it extremely difficult to study the properties of aerosol in the upper atmosphere. For this

purpose, balloon-borne and/or preferably aircraft-mounted photometers would be extremely useful.

A portable and rigid filter photometer is being constructed for measurements in the spectral region 3100-10,000A. Attempts will be made to achieve an accuracy of a few per cent in the measurements of absolute intensities of the radiation in about eight different spectral regions of equally high spectral purity. A computer program was developed to determine the magnitude of spectral impurity introduced in the filter photometric measurements of the direct solar radiation at the ground by the wings of the standard interference filters. It was found that the filter photometric instruments have serious limitations in terms of spectral purity of which some may be overcome by judicious selection of filters and photocathode combinations. Use of a conventional monochromator has not yet proved to be absolutely essential for this type of work. A joint paper related to the design of the proposed filter photometer and findings of the numerical studies was presented by Blifford and Furukawa(V).

Most of the major component parts of the photometer have been received and a program is under way to make careful measurements of the characteristics of the photomultiplier, filters and neutral density wedges using the Cary spectrophotometer. A controlled temperature chamber is being built to obtain precise data on filter characteristics. A low-level light source of over-all stabilities of better than one per cent, developed successfully by Blifford, will be used as an internal calibration standard. He is now working on over-all temperature compensation for the instrument. A manually operated model of the instrument should be ready for ground-based observations by the summer of 1964. Preliminary measurements will then be carried out from nearby mountain locations (over 12,000 ft) to evaluate the sensitivity of the instrument under favorable conditions of reduced contribution from low-level haze and multiple scattering.

It is planned to have a series of observations from aircraft to obtain the extinction coefficient at several wavelengths from direct sun measurements over different geographical areas and weather systems.

Reliable data of this nature taken from a constant altitude of about 25,000 ft (or higher) would be very useful in several studies. Similar measurements of extinction coefficients at several heights (5,000-30,000 ft) over a pre-selected site will be used to obtain size distribution and concentration of the atmospheric aerosol with height.

It is proposed to use this instrument eventually from aircraft to measure the spectral brightness and polarization of the sky during twilight. Such measurements would be extremely useful in studying the day-to-day variations of density and dust distribution in the upper atmosphere.

IV. Papers Published, 1963

Dave, J. V., P. A. Sheppard, and C. D. Walshaw: "Ozone distribution and the continuum from observations in the region of 1,043 cm^{-1} band," Quarterly Journal of the Royal Meteorological Society, vol. 89, pp 307-318, 1963.

V. Papers Presented, 1963

Welford, W. T. and I. H. Blifford: "Ozone spectrophotometer," presented at the joint session of the American Meteorological Society and the Instrument Society of America, Chicago, September 9-12, 1963.

Blifford, I. H. and P. Furukawa: "Balloon-borne photometer," presented at the joint session of the American Meteorological Society and the Instrument Society of America, Chicago, September 9-12, 1963.

VI. References

Dave, J. V. and P. Furukawa: "The effect of Lambert-type ground reflection on Umkehr measurements," Journal of the Atmospheric Sciences, March, 1964.

Dave, J. V.: "Importance of higher order scattering in a molecular atmosphere," Journal of the Optical Society of America, March, 1964.

Air-Surface Interactions

J. W. Deardorff, G. M. Hidy

Introduction

Fundamental laboratory work and numerical studies are under way in efforts to understand better the interactions between the turbulent air and the underlying surface. The objective is not to model atmospheric phenomena, but to examine and to explain turbulent interactions in simplified systems containing the more important features of atmosphere-surface interactions. Dr. Deardorff is studying parallel-plate convection with an elongated convection chamber, and two-dimensional convection as an initial-value problem using the digital computer. Dr. Hidy is studying air-water interactions with a combined wind-tunnel and flume located at Colorado State University. In addition to these studies, he is working on two problems in the physics of aerosols. These include condensation and coagulation processes, and motion of small particles in non-uniform gases.

Past and Present Work

1. Convection studies

Experimental. The convection chamber has been completed, and can produce Rayleigh numbers in the turbulent regime for air from 10^5 to 10^7. Sensors which can measure horizontal and vertical velocity components, temperature, and small-scale temperature gradients have been constructed and mounted on a carriage which can traverse horizontally a ten-foot distance within the chamber at a nearly uniform speed. Measurements may be taken at desired levels between the parallel aluminum plates. The basic sensors are two 1.7-mm hot wires mounted on a V and inclined $\pm$ 45° from the horizontal, a 1-mm length of .000025 in. platinum resistance wire for fast-response temperature measurements, a pair of such wires mounted on a different probe for temperature gradient measurements, and a small thermocouple not mounted on the carriage. Sum and difference signals from the two hot wires may be measured simultaneously. Any two of the following quantities: u, w, T, $\delta T/\delta y$, $\delta T/\delta z$, from sensors on the moving probe, and temperature from the thermocouple located at a fixed point within the chamber, may at present be simultaneously recorded on a strip chart and on half-inch magnetic tape. Tapes are compatible with recorders in the analogue system at the Civil Engineering Department at Colorado State University, where analysis may be made for root-mean-square values, correlations, frequency spectra, and probability distributions.

Preliminary results give heat transports dependent upon Rayleigh number in excellent agreement with findings of Globe and Dropkin (1958), and temperature variance very similar to that measured by Thomas and Townsend (1957). Calibration of sensors is in progress to permit measurement of velocity-dependent quantities not previously observed for this problem.

Numerical. The study of two-dimensional convection within a region of width equal to height, or to twice the height, has been completed. Results have been submitted to the Journal of Atmospheric Sciences. The study was for air at the particular Rayleigh number of 6.75×10^5 in order to allow comparison with experimental results of Thomas and Townsend. The two-dimensional hydrodynamic and thermodynamic equations, with the Boussinesq approximation, were integrated with respect to time, starting with various initial conditions. In all cases nearly steady-state solutions were eventually obtained in contrast to experimentally observed turbulence. This failure is attributed to the two-dimensional assumption and limited width-to-height ratio. In order to extend such a study to three dimensions, it appears necessary to use a much coarser grid network in the numerical computations. Small-scale Reynolds fluxes may then no longer be negligible, but might be represented by suitably chosen small-scale eddy coefficients. Despite the absence of computed turbulent motions, the heat transport agreed within 34 per cent of the experimental value. The numerical value was too small for the case of width equal to height (lateral, insulated walls), and small corner eddies then present could be seen to suppress the heat transported by the large-scale vortex. For the region of width equal to twice the height, the heat flux was slightly too large, and the effect of corner eddies was then diminished. The study thus gave some picture of the role of smaller eddies in diminishing the heat transport of the largest scale eddies.

A method of estimating small-scale eddy coefficients was worked out for problems where the small-scale flux averaged over a grid area is primarily associated with effects of truncation upon larger-scale, computed motions. The method was reported at the December 26-28 AGU meeting in Boulder, Colorado. Since that time, however, it has been discovered that the small-scale Reynolds fluxes which the eddy coefficients are supposed to represent are frequently much smaller than errors arising from truncation and from acceptance of Reynolds' averaging assumptions. Further study is continuing on this point.

Efforts to approximate terms involving the third or "y" dimension within the two-dimensional numerical framework were finally discontinued. In all attempts, the assumptions concerning these terms were not good enough to prevent, for example, local regions of extreme temperature from appearing.

2. Air-water interaction studies

Experimental. An investigation of the mechanism for mechanical energy transfer across an air-water boundary is in progress. Experimental work has been undertaken in the 2 x 4 ft cross section, 60-ft-long wind tunnel-flume combination located at Colorado State University. Measurements are being made of the development of surface waves on still water with varying air flow and water depth. The wavy surface is recorded photographically. At the same time, the amplitudes of waves are measured at several stations downstream with a wire capacitance gauge. The wires measure the variation in depth to 0.001 in., with a response time of about 0.01 second. The data from the gauges are recorded on a "visicorder" oscillograph. Preliminary results show that: (a) for constant water depth, the length and amplitude of the waves increase with increasing air velocity, (b) at constant air velocity, the amplitude and the wave length increase with distance downstream from the leading edge of the water, (c) there is interference occurring during the development of the wave pattern, and (d) below air velocities of about 10 ft/sec, no waves develop on the water.

The response of a pitot tube placed in the air flow and a hot wire anemometer has been traced on the visicorder along with the wave pattern. Vertical profiles of velocity taken with the pitot tube showed that there was a kink in the distribution 6-8 in. above the mean surface of water. In other words, a zone of high velocity flow, a jet, appears to exist in this region above the water. Measurements of the mean values and the fluctuating components of air velocity were taken at approximately 1/8-1/4 in. above waves of 1 in. maximum amplitude (air flow of about 20 ft/sec, measured at 6 in. above the mean depth of water). The dynamic pressure measured by the pitot tube indicated that there was acceleration of air over the crests and deceleration in the troughs of waves. Both the kink in the velociety profile, and the acceleration and deceleration of air close to the surface also have been observed by an interesting flow visualization technique using helium bubbles (Schooley, 1963).

Turbulent fluctuations up to $\sim$100 cycles/sec were examined and compared with the wave patterns. These data showed that bursts of relatively high turbulent intensity developed just behind crests of some, but not all, waves. The bursts decayed before reaching the windward side of the next wave. These observations indicate that separation of the air flow from the wavy surface occurred at least part of the time. The decrease in intensity in the trough is probably the result of:
(a) diffusion of the turbulent wake outwards into the free stream, and
(b) reduction of turbulent intensity by the action of the converging and accelerating flow in the front of the next wave. Comparison of the turbulent velocity with the wave profile also indicated that there was some connection between regions of higher turbulence intensity and small ruffles on the water surface which were superimposed on the primary pattern of waves.

Records of the wave patterns were converted into digital form. They have been analyzed to determine the autocorrelation functions and the power spectra. In many cases, the spectra showed one primary component with a small secondary peak located at a frequency slightly less than twice the principal frequency. It is not clear whether these bimodal spectra are the result of non-linear interaction of components of different frequency, or of the effect of reflection from the "beach" at the ends of the tunnel. Two of the spectra taken at 36 ft downstream from the leading edge of the water, with air speeds of 30 and 35 ft/sec, displayed the inverse fifth power relation for the high frequency region as predicted by Phillips (1958).

3. Aerosol studies

Condensation and coagulation processes. A report of the results of the studies of vapor condensation in the mixing zone of a jet has been published in the January 1964 issue of the A.I.Ch.E. Journal. A short note discussing the relation between the classical analysis of mixing and the more modern theory based on the transport processes has been published in the Journal of Applied Meteorology (August, 1963).

A coagulation chamber consisting of a large drum which rotates on an axis parallel to the earth's surface has been suggested by Dr. Alexander Goetz (California Institute of Technology). The rotation of fluid in the chamber tends to counteract the gravitational settling of small particles. If the rotational speed is properly adjusted, the particles will tend to move in small inertial circles. The diameter of the circular paths depends on the size of the particles. Growth by coagulation or condensation as well as motion resulting from thermal or diffusional forces in the chamber can be observed as changes in the circular motion of the aerosol particles. The rotating chamber has been designed and construction work is under way.

Numerical integration of the coagulation equation has been carried out for several different cases. The classical results of Smoluchowski (Chandrasekhar, 1943) have been extended to charged and uncharged, (slightly) polydisperse aerosols. Examples where the coagulation constant based on the Stokes-Einstein diffusivity is modified by the Cunningham correction were also considered. Some of the results are as follows: (a) a slightly polydisperse distribution of particles will broaden its size spectrum faster than a monodisperse sol, (b) a distribution which initially contains a gap in particle size will fill in the space relatively slowly by coagulation of the smaller sized particles, (c) unipolar charge has little effect on coagulation if the charge is weak; when the charge is strong, coagulation is suppressed, and (d) the Cunningham correction increases the coagulation rate of a monodisperse sol.

Motion of particles in a non-uniform gas. The literature discussing the forces acting on particles in gases containing concentration or temperature gradients has been reviewed. The theoretical treatment has been worked out in some detail in a number of recent papers. However, there is a need for more experimental work to verify many of the theoretical predictions particularly in the range where the diameter of the particles is less than, or equal to, the mean free path of the gas.

Future Plans

1. Convection studies

Experimental. a.) Measurements will be taken of the accessible terms of the turbulent kinetic-energy and temperature-variance equations as a function of distance from a boundary, for several different Rayleigh numbers between 10^5 and 10^7.

b.) Measurements of the appropriate statistical averages for the stably stratified case when a source of kinetic energy exists at the lower boundary could be made in the convection chamber. We hope to explain how the sharpness of the inversion base is maintained (rather than being smoothed) by turbulence from below, and to relate the steady-state height of the inversion base to the over-all static stability and intensity of mechanical turbulence being supplied.

c.) The convection chamber can be equipped with a rotating belt of fine-mesh wire atop the lower plate, with the ends of the chamber open. Measurements of the appropriate quantities for plane Couette flow with convection could be undertaken for a small plate separation for various Rayleigh and Reynolds numbers.

Numerical. Before extending the two-dimensional convection problem to three dimensions, it appears desirable to utilize a more dense grid near the boundaries than in the interior. If this is done successfully, then the problem will be extended to three dimensions using a coarse grid and small-scale eddy coefficients in the interior. The three-dimensional problem now appears best approached with the primitive equations, solving for pressure, in order to avoid solving three Helmholtz equations for three stream-function components each time step.

2. Air-water interaction studies

a.) Measurements of wave profiles and the average and fluctuating velocity of air will be continued at Colorado State University.

b.) Attempts will be made to make a carriage for the pitot tube and the hot wire anemometer which will follow the wavy surface. This should enable us to get a better picture of the details of the air motion near the water, especially in the important region where the air velocity equals the wave velocity.

c.) Movies of the development of a particular wave will be taken by using a camera placed on a carriage traveling parallel to, and at the same speed as, the wave.

d.) Studies of the generation of waves on moving water will be initiated. The water motion will be examined with dye tracers. If may be possible to trace the generation and spread of rotational motion near the surface of the water by tracer techniques.

e.) An air heater consisting of calrod bars and a grid of steam tubes will be installed in the entrance section of the wind tunnel-flume combination. A large heater will also be added to the sump. Experiments will be started to determine the effects of density differences on the patterns of air and water flow. A study of the variation in the rates of convective transport of heat and matter with changes in temperature and humidity will also be undertaken.

3. Aerosol studies

a.) Construction and check-out of the coagulation chamber will continue. The motion of aerosol particles will be observed through a microscope. Coagulation rates of aerosols will be checked by sampling gas from the chamber and passing the sample through a Goetz aerosol spectrometer.

b.) Numerical calculations of the effect of concentration and temperature gradients on the coagulation rate of aerosols are planned.

c.) The coagulation chamber will be modified eventually to study the motion of small particles in concentration and temperature gradients.

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Atmospheric Ozone and Stratospheric Circulation

Hans U. Dutsch

Group Members

In June 1963 Dr. A. Barrie Pittock from Melbourne, Australia, visiting the United States on a Fullbright fellowship, joined the staff. He will work on this project until fall 1964. In August, 1963, Dr. Soren H. H. Larsen from the University of Oslo, Norway, joined us for a nine-month period. Since November, 1963, Mr. Peter Crooimans has been working with us as a technician for the ozone sonde program; in December Miss Carol Eisele was appointed as half-time computational clerk.

Work in 1963

Work in the first half of the year was mainly of a theoretical nature. The photochemical equations were adapted to the electronic computer for the equilibrium as well as for the non-equilibrium case. The main aim of the study is to try to determine some of the parameters, entering the equations, which are not known well enough by comparing theory and observation at levels where agreement can be expected. Preliminary results were reported at the Third Western National Meeting of AGU in December. Work was also started on the photochemical theory of ozone and atomic oxygen in the mesosphere.

Larsen began an investigation of the circulation in the equatorial lower stratosphere based on observations of ozone and radioactive material and on results of the above mentioned photochemical study.

The Umkehr observations obtained at Arosa since 1961 under an Air Force contract were evaluated on the computer and the results were published and discussed in two reports. The observations obtained by the same plan during the 1956-1959 period were reevaluated for obtaining a consistent set. In the second report mean values based on almost 1500 single observations were presented.

Mr. C. Mateer from the University of Michigan at Ann Arbor, who was here on our summer visitor's program, started work on an improvement of the Umkehr evaluation procedure which has so far not been able to show any secondary maxima. He developed a method which, under certain conditions, can show a second low-stratospheric maximum, and he is now continuing work on this problem as his doctoral thesis.

In late summer we started an ozone flight program which will be a major part of our work during the coming years. One main purpose of these flights is to supplement the measurements of the American ozone sonde network, which are done once per week, by an observational program more continuous in time. It was not possible to fly as often as we would have liked with this plan in mind; however, during the most interesting part of the year we will be able to launch 3-4 times a week which will give us -- together with the network flights at Fort Collins -- a fairly good coverage in time at least for that period.

For this flight program we chose the Mast version of the Brewer bubbler sonde which in principle should give an absolute measure. Prof. Alan W. Brewer (University of Toronto), who was here under NCAR's summer visitor's program, helped us to get the flight program started. After that Pittock and Crooimans were mainly working in this field. Though there are still sporadic difficulties with the sondes -- on the solution of which we are collaborating with the manufacturer -- we are already getting useful and interesting results.

Present Work

As part of the above described ozone sonde program and also in the interest of a rapid development of a world wide ozone sonde network, we organized an intercomparison of different types of ozone sondes in early 1964. Six different sondes were flown: The Mast version and the British version of the Brewer electrochemical sonde (the latter by Mr. D.B.B. Powell from the British Meteorological Office), the Regener chemoluminescent sonde (flown by Louis Aldaz of the University of New Mexico), Paetzold's optical sonde (flown by Mr. F. Piscalar of the Institute for Geophysics and Meteorology of the University of Cologne, Germany), and an optical and a chemical sonde (titration type) developed in Japan and flown by Dr. J. Kobayashi, Mr. Y. Sekiguchi, and Mr. H. Muramatsu of the Japan Meteorological Agency. At the same time Umkehr observations were carried out with our new Dobson instrument. The results are being worked up now but it is already obvious that the experience obtained will be very helpful for the further development in the field.

Pittock is building up his experiment, initially developed in Australia, of observing vertical ozone distribution by measuring sunlight reflected from a constant level balloon at sunset or sunrise. In a second internal intercomparison this method will be checked against Umkehr observations and the Mast-Brewer type ozone sonde in spring and summer 1964.

Our Dobson instrument arrived in the fall of 1963. Larson is working on its calibration (the calibration given by the manufacturer has to be carefully checked). Mr. C. Tibbals (working with us on a consulting basis) is making the instrument self-recording.

Future Work

The ozone sonde soundings will be continued on an increased time rate, and a long term intercomparison is planned with Umkehr observations starting as soon as the Dobson is self-recording. A technician will be needed to operate this instrument and to evaluate the results.

The theoretical work on ozone photochemistry will be intensified and results will be compared with these from our ozone sonde flights and from the American ozone sonde network to gain more insight into stratosphere circulation. This is going to be the central part of the work done under this project. Assistance from a full-time skilled applied mathematician will eventually be needed for this purpose.

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Atmospheric Physics

Guy Goyer

Group Members

The research team was assembled in 1963. On February 1, 1963, Robert L. Perdue was hired as laboratory technician for the shock wave project. The following month, Mr. Robert D. Watson joined the crew as research assistant to launch and take charge of the laser meteorology project. In April, 1963, George A. Hallenbeck was hired as a laboratory helper on the laser meteorology project. Mrs. Sonia Gitlin, the first to join the group in October, 1962, and hired as part-time secretary and part-time laboratory technician, devoted full-time in the laboratory as of September 1, 1963 when Miss Paula Russ was hired as full-time secretary for the research group. Finally, on October 1, 1963, Dr. Tarani C. Bhadra joined the group as research associate in charge of the shock wave project. An electronic engineer will be hired soon to complete the staff for the following two years. In addition, it is planned to hire a couple of high school or university students to help in the proposed field work.

As indicated above, this program consists of research in two main areas:

A. The Effect of Shock Waves on Hydrometeors

B. Laser Meteorology

Past Work

A. The Effect of Shock Waves on Hydrometeors

The purpose of this project is to better understand the effect of lightning discharges, considered as shock-wave generators, on hydrometeors such as hailstones, large cloud droplets, and supercooled water droplets. Two studies were initiated this year in this area: the weakening of simulated hailstones, and the triggering of freezing of supercooled water samples.

A shock tube was designed and built for these studies. The shock tube consists of a 12-in.-diameter, 8-ft-long reinforced cardboard expansion chamber and a 4-in.diameter, 1-ft-long compression chamber separated by cellophane or cellulose acetate diaphragms. Sample ports and observation windows at every foot of the expansion chamber permit observation by optical means of the samples within the tube. The shock tube can be cooled down to a temperature of about -15°C by the circulation of a coolant from a 50-gallon constant-temperature bath. Shock wave over-pressures ranging from a few tenths of a psi to about 20 psi can be generated by the breaking of plastic diaphragms or by the detonation of an electric blasting cap. The shock tube was calibrated by measuring the shock wave over-pressure as a function of distance from the diaphragm and as a function of the pressure behind the diaphragm. A Kistler gauge and amplifier system was used with an oscilloscope for this calibration. Samples can now be exposed to shock waves of known intensity ranging from 0.1 psi to 20 psi.

The study on hailstones consisted in refining the earlier experiments of Goyer and Favreau in an effort to reproduce their results. Goyer and Favreau reported in a still unpublished paper that a 1.1 psi shock could trigger cavitation within the liquid phase of the hailstone model leading to a weakening of its ice structure. These conclusions were based on the theoretical confirmation that a shock wave can give rise to an oscillating pressure pulse within an ice cube, and on the observation of air bubbles and ice structure cracking after the exposure of the simulated stones to a shock wave of known intensity. Gitlin worked with clear and cloudy ice and generated internal water pockets by several means. In the case of ice cubes containing a wire, she observed the generation of bubbles and occurrence of cracking caused by the refreezing of the liquid pocket even in the absence of a shock wave. Injected water pockets invariably produce the same phenomenon. No further effects of shock waves could be observed when refreezing was eliminated. She has also observed totally enclosed cavities produced by melting around a short wire or small copper plate totally imbedded in the ice. These samples were exposed to a 1.9 psi peak over-pressure, 40 micro-seconds duration shock wave and to a 1.1 psi 2 millisecond shock wave respectively. The appearance of bubbles or of cracking could not be observed in either case under 80X magnification. As far as we can measure, our shock wave parameters are within the range for triggering cavitation under these experimental conditions.

A pneumatic hail crusher has been built with which we hope to accurately determine the strength of ice cubes exposed or not exposed to shock waves. It will be used in an effort to detect the decrease in crushing strength of ice cubes exposed to shocks as reported by Goyer and Favreau. It will also be used in the field to determine the crushing strength of freshly fallen natural hailstones exposed or not exposed to shock waves.

In view of the observation of the triggering of freezing of supercooled water samples by a shock wave, discussed below, theoretical studies of side effects on hailstone growth have been carried out and showed that a substantial decrease in impact strength could result from the growth of the hailstone in an ice crystal cloud as opposed to growth in a supercooled water cloud. Growth in an ice crystal cloud would lead to a decrease in the rate of growth of the hailstones, to a reduction in density, in fall velocity, and in impact energy, since part of the impact energy would be absorbed by the layer of mushy snow grown around the solid core. As a result of these effects, about 90 per cent reduction in impact energy should be expected from a hailstone grown in an ice crystal cloud as opposed to one grown in a supercooled water droplet cloud.

The study of the triggering of freezing of supercooled water droplets was also initiated in early 1963. The preliminary work was done with 0.25-0.5 cc samples of water contained in glass or plastic tubes. The freezing of the samples was observed by optical means and temperature measurements. The results obtained show, without doubt, that under these conditions, a shock wave over-pressure of around 2 psi and of 2 millisecond duration can trigger the freezing of the supercooled water sample at a temperature warmer than its natural freezing temperature. The wall effect of the container has been studied by carrying out this same type experiment in several container materials. Tests were made in glass, tygon and polythene tubes with consistent results in all cases. Preliminary work on free droplets suspended from capillary or on spider web screens has been started. Serious difficulties have been encountered in working with such systems and a better technique is now being sought.

In order to confirm these results on free-falling droplets, several experiments were attempted in the plume of Old Faithful at Yellowstone Park in January. Two field tests were carried out and performed by detonating 100 ft of 56-grain primacord suspended from a captive balloon. In both cases, a short wave of microhail pellets was observed to fall out of the plume of Old Faithful seconds after the blast. Unfortunately, the weather conditions did not permit carrying out more tests to yield very conclusive results. However, we are hopeful that this effect can be tested in the low supercooled clouds hanging over the mountains of Boulder.

Theoretical studies on the intensity of shock waves generated by lightning has also continued. Practically no field measurements exist in such an area. Consequently, we have estimated the pressure decay curve of a lightning discharge by several methods. Lightning of three-inch core diameter and 25,000^{o}C was assumed as a working model. The energy of the gas within the core, suddenly heated to that temperature, was calculated and assimilated to that of a charge of TNT. Scaling down equations were used to calculate the pressure decay curve of the lightning from the well-known pressure decay curve of a four-pound TNT charge. Moreover, the equations for estimating the decay of the sonic boom in air were also used together with a rough approximation equation to calculate the pressure decay of lightning. It is highly possible that the shock wave over-pressure is smaller than evaluated. All three methods gave order of magnitude agreement within themselves. This computation, we feel, leads to a maximum pressure for lightning. An interesting result of this computation is that the calculated pressure decay curve for lightning is very similar to that measured and calculated for 40-grain primacord. Assuming the shock wave over-pressure threshold values for triggering the freezing of supercooled water as determined by Morin and Medard (1), and for triggering cavitation within hailstones as determined by Goyer and Favreau, the volume of clouds affected by a lightning discharge was estimated. In spite of the rapid decay of the shock wave generated by lightning, enormous volumes of clouds could be affected by lightning. Considering the large number of lightning discharges, their effect on the further development of clouds might be much larger than anticipated. On the basis of these calculations, cavitation could be triggered within hailstones in a volume from 10^3 to 10^4 cubic meters by a single lightning stroke. Similarly, the triggering of freezing of supercooled water droplets could be produced by a single lightning stroke 5000 ft long in a volume ranging from 2×10^4 to 7×10^5 cubic meters depending on altitude. The large number and the great length of lightning discharge in a thunderstorm could certainly have a major effect on the hydrometeors within that thunderstorm.

A minor project successfully carried out over the past year has been the laboratory and field testing of a new high-efficiency cloud seeding device called "Weathercord." "Weathercord" consists of standard primacord, a cord explosive widely used in mining and construction industries, to which a gram per foot of silver iodide has been added. A joint development of Canadian Safety Fuse of Brownsburg, Quebec, Canada, and Weather Engineering of Montreal, Quebec, Canada, the terylene wrapped cord contains 49 grains/ft of pentaerythritol tetranitrate, a primary explosive, and 12 grains/ft of silver iodide. Its detonation velocity is 5465 m/sec or 17,925 ft/sec. The output efficiency of this generator was measured with the help of Professor Lewis Grant at Colorado State University. Two, 1½ ft lengths of "Weathercord", suspended at the center of a 3-ft-diameter 3-in.-wall reinforced concrete culvert section were detonated in the hydraulic laboratory which is about 125 ft long, 50 ft wide, with a 40-ft ceiling. After a few minutes of mixing through forced circulation of eight powerful fans, Professor Grant sampled the air in 40-cc syringes at different locations in the lab. The nuclei count was made in a cold chamber maintained at 20°C below zero. In spite of the small relative concentration of nuclei in this huge air volume, a count of about 10^{14} nuclei per gram of silver iodide detonated could be determined. This figure is quite firm and is comparable with the output of most commercially available generators. At Yellowstone Park, the plume of Old Faithful geyser was seeded with 100 ft of "Weathercord" strung from a captive balloon, anchored at about 250 ft from the ground. In all three tests carried out, the concentration of ice crystals in the air increased three or four orders of magnitude, five or ten minutes after detonation. One of the tests was carried out at a temperature of -22.5°F and gave rise to prisms which produced very vivid optical effects. All in all, these tests were very successful. The primary advantage of this silver iodide nuclei generator is its capacity to inject into a large layer of clouds a large number of ice nuclei in the order of microseconds.

B. Laser Meteorology

The purpose of the laser research program is to evaluate laser sounding systems for the determination of both lower and upper atmospheric parameters. The program has been separated into three phases: feasibility studies, laboratory research, and field research. The feasibility studies originally evolved around the Mie theory for the extinction of electromagnetic radiation by means of absorption and scattering. In order to determine the structure of fogs and clouds in the atmosphere by optical means, it is necessary to correlate scattering (or extinction) measurements with theoretical calculations resulting in uniquely predicting the measured scattering pattern. The scattering equations as determined by the Mie theory were programmed for computer solution and results were obtained for those complex indices of refraction corresponding to the principal laser wavelengths available at that date. Using the results, a computer program was written which attempted a least squares solution for the aerosol distribution N(r)dr giving rise to a particular scattering pattern. Since a unique solution could not be obtained by this technique, it was felt that a different approach was necessary; it is currently being pursued. The possibility of upper atmospheric probing for the determination of aerosol sizes and distributions, particularly of the dust distributions described by Professor Christian Junge (of the Johannes-Gutenberg University, Institute of Meteorology and Geophysics), and others, at altitudes of from 20-30 km was also examined. It was demonstrated that with powers of ten megawatts or greater, available from Q-switched lasers, and low noise receivers, signal to noise ratios greater than unity could be obtained when probing at lower altitudes at scattering angles of up to 40°. Moreover with low noise receiving systems and photon counting techniques, sounding to heights of 140 km or greater can be achieved. Future efforts will be directed toward this most interesting area of laser research. Some of the ideas of this study were published in a conceptual type of paper in the Bulletin of the American Meteorological Society in August, 1963.

The laboratory program involved the design of experiments to test concepts of measurements with laser systems. A fog and cloud chamber was constructed. Two spray nozzles produce water drops in the size range of 1-5 microns and 5-25 microns. The 17-ft chamber was designed for both short and long path absorption and scattering measurements along a single horizontal axis or along a folded path. Moreover by tilting the chamber into a vertical position, measurements can be made on a settling fog. Optical density studies were made in the fog chamber with a Q-switched ruby laser of approximately one megawatt peak power output. This study accomplished two purposes -- evaluation of the ruby laser as a cloud probe and evaluation of the fog producing mechanism in the chamber. As a result of this study, a better control of the fog generator was developed and a more rigorous calibration of the fog generated is currently being obtained.

With the success of the upper atmospheric probing program in mind, research was directed to achieving maximum sensitivity and minimum noise in our receiving system. Utilizing low noise techniques employed by the National Bureau of Standards, a receiving system was built using an RCA 7265 photomultiplier tube. Measurements of the dark current in the tube revealed noise pulses of approximately 100 per second which is as good as could possibly be achieved with this type of photomultiplier. An EMI 9558B photomultiplier was then ordered, in which it is hoped to achieve a noise pulse count of no more than one per second. This would permit photon counting techniques to be employed when extremely low intensity scattering is to be detected. In both the laboratory and field research program, a rented ruby laser was acquired and tested for a period of three months. Laser ranging experiments on buildings were performed and one cloud height probe was attempted with only moderate success due to low cloud ceilings which resulted in an overlap between transmitted and received signals. With the acquisition of a permanent laser system, cloud ranging experiments will be performed to determine cloud base and height.

A helium-neon gas laser has been recently acquired for both laboratory and field studies. In the laboratory, the gas laser will be utilized as a source of coherent radiation for angular scattering measurements in the cloud chamber. This laser was taken on the Yellowstone Research Expedition to measure the scattering cross section of both water and ice clouds and to study diffraction effects produced by the natural fogs in the Yellowstone basin. Due to frequent periods of unfavorable weather, the experiments were not conducted and future plans include measurements in the Boulder and Climax areas. However, measurements of the pulse spectrum of the radiation scattered by snow crystals were made during the Yellowstone field trip and will be analyzed in the near future.

Future Work

A. Plans for Fiscal Year 1965

1. The Effect of Shock Waves on Hydrometeors

a. The laboratory work will continue on the triggering of the freezing of supercooled water samples with major emphasis on droplet work. The lab study on simulated hailstones should be terminated early in FY-1965 and the study of droplet shattering will be initiated.

b. Field studies for FY-1965 will embrace the measurement of the impact strength of fresh natural hailstones exposed or not exposed to a shock wave of known intensity; thunderstorm seeding with Weathercord; design and evaluation of a field network for measuring the intensity of shock waves generated by lightning.

2. Laser Meteorology

   a. The laboratory study on the determination of fog droplet size distributions through the measurement of scattered laser radiation at several wavelengths or scattering angles, or through diffraction patterns will be initiated.

   b. The field work will consist in attempting to detect the phase change in a supercooled cloud turning to an ice fog with back scattered laser radiation; evaluating techniques for ranging clouds and studying cloud microstructure and cloud growth; and in probing for the high altitude stratospheric dust layers.

B. Plans for Fiscal Year 1966

1. The Effect of Shock Waves on Hydrometeors

   a. The laboratory work will consist in reproducing lightning in the shock tube by using a high intensity spark discharge as a shock wave generator. The combined effect of the shock wave and of the ions released on supercooled and warm droplets will be studied.

   b. The field work will embrace collecting of data on the intensity of shock waves generated by lightning in the field and aboard aircraft; and, thunderstorm seeding with primacord containing sodium chloride.

2. Laser Meteorology

   a. The laboratory study of a Doppler system for detecting velocities in cloudy and clear air will be initiated.

   b. The field work will consist in testing the Doppler system for cloud droplet size measurements and for the detection and measurement of clear air turbulence parameters.

<u>Reference</u> (1)

Morin, J. and L. Medard: "Congelation distance d'un nuage sur fondu par ondes de choc," <u>Compt. Rend. Academy of Sciences</u>, <u>225</u>, 432, Paris, 1947.

Publications in 1963

Goyer, G.G. and R. Watson: "The laser and its application to meteorology," Bulletin of the American Meteorological Society, 44, 9, pp.564-590, September, 1963.

Goyer, Guy G.: "The formation of nitric acid mists," Journal of Colloid Science, 18, 7, September, 1963.

Crystallography

Charles Knight

Chronology

In September 1963 Knight started a one-year visit to the Department of Physics, University of Hokkaido, Sapporo, Japan, as a participant in the program of Japanese-United States scientific cooperation sponsored by the National Science Foundations of the two countries. The work of the program has continued uninterruptedly despite this change of locale.

Past and Present Work

The work on spherulitic crystal growth briefly discussed in the Annual Report of 1962 has proved of such basic importance and interest that the work in the present year has been almost entirely on this subject. Spherulitic crystallization is a general phenomenon, and a systematic one, which may occur in any one-component system with sufficient supercooling of the liquid. Knight's opinion differs from that of some other workers who think that impurities are requisite for spherulitic crystallization. The difference of opinion is not easily resolved by experiment because of the difficulty of "sufficiently" supercooling many liquids and the impossibility of attaining absolute purity.

The work during the past year has been to gather as much information on the systematic aspects of spherulitic crystallization in as widely varying materials as possible; to generalize the information to features that do not depend on unique properties of individual materials or classes of materials; and to attempt to arrive at a general theory of the phenomenon. The first two steps in this process may be complete; about a dozen materials have been studied in some detail, and generalizations have been made and checked with other materials. Several tentative theories have been disproved to Knight's satisfaction by designing simple experiments to test them.

A theory of spherulitic crystallization is being completed at present.

Although the relation of spherulitic crystallization to atmospheric research may seem somewhat far-fetched, it is thought that an acceptable theory of spherulitic crystallization will be of fundamental importance to any discipline in which crystal nucleation and growth are important, including cloud physics. The study of spherulites began in an investigation of ice spherulites, and its main emphasis has remained on ice. The study of other materials was begun because it seemed the only way to solve the problem presented. The study was carried to greater lengths when it became evident that a general and significant crystallization phenomenon was involved.

Future Work

In the immediate future, work will be performed with the object of explaining snow crystal habit changes. Experiments to date have examined snow crystal growth from various gases supersaturated with water, drawing conclusions on the effect of the host gas on snow crystal habit in terms of the diffusivity of water vapor in the gas. It is proposed to do exactly analogous experiments on the growth of snow-like crystals from organic liquids which have limited miscibility with water. The liquids will be selected to give a range of solubility of water and of chemical type. The apparatus to be used is a diffusion chamber analogous in every detail to Hallett and Mason's apparatus (Proc. Roy. Soc. 247A, 440). A pilot experiment using ethylene dichloride has reproduced all fundamental aspects of Hallett's experiment except the ice crystal habits, which are different. In the upper part of the chamber, above the freezing level, one gets a "cloud" which disperses upward with time taking the "condensation nuclei" with it. (This cloud has the additional peculiar feature that it is layered.) Fine dendrites of ice ("dendrites" not implying a specific orientation here) grow profusely on the central fiber below the freezing level. A more elaborate apparatus which will allow easier observation is being constructed.

Work is continuing in the cold room on various aspects of lake ice growth, as mentioned in the annual report of 1962.

Computing Facility

Glenn E. Lewis

Group Members

The Computing Facility has grown a great deal in 1963. Dr. John M. Gary joined the staff as a research mathematician and has been doing some detailed study on the stability of certain finite difference schemes. Raymond Essert and Paul A. Rotar were hired as systems experts. When Essert left, David L. Kitts took over his position. In order to accommodate the increased computing load the following people joined the staff as programmers; Robert P. Biro, Chester W. Ellis, Jr., Alan C. Kay, Jack S. Miller, Frederick W. Nagle, Paul N. Swartztrauber, Loren K. Wagner and W. Hugh Walker. Cynthia Croft joined the staff as secretary to Dr. Lewis. Suzanne Hedgecock was hired as a key puncher and Gary O. Meeker as an EAM operator and messenger.

Present Work

Because of the rapid growth of use of the National Bureau of Standards' IBM 7090 by all concerned (NCAR as well as NBS), it became increasingly clear that this machine could not provide enough computing power for NCAR for the period prior to NCAR's purchase of a large computer of its own. Although NBS cooperated in every particular, the service was slow and at the same time rental costs were quite high. It was also clear that the experience of running an interim computer would be invaluable. As a result, after careful evaluation of all existing computers in the same class as the IBM 7090, NCAR entered into an agreement with the Control Data Corporation on May 9, 1963 to rent the Control Data (CDC) 3600 and other peripheral equipment. Although it is too early to determine the amount of use of the 3600, it is clearly increasing rapidly. It seems most likely that we will have saturated one shift of the 3600 by July 1, 1964.

The CDC 3600 has 32K 48-bit words of memory and is as fast as any commercially available computer. Attached to the main computer are eight high-speed tape drives. A 160-A was rented as an off-line peripheral processor. Attached to this are two high-speed tape drives, a 1200-cards-per-minute card reader, a 1000-lines-per-minute printer, and a 100-cards-per-minute punch. The total system was in operation on December 4, 1963 in the basement of the nearly completed Physical Science Research Building #2. The facility also includes four key punches, a verifier, a reproducer, a sorter and an interpreter. Edward A. Germann has joined the staff as the machine room manager and Benjamin J. Klepac as a computing machine operator.

The time between the decision to rent a computer and the installation of the 3600 was only seven months. Special thanks for this remarkable achievement should go to Colson for preparation of the site and to Rotar and Kitts for programming and debugging our operating system.

There has been continued effort to determine which machine NCAR should purchase in the future. Letters requesting information on large computers were sent to twelve leading computer manufacturers. Of these, Burroughs, Honeywell, CDC, and Feranti responded positively. Of the machines proposed, the CDC 6600 seemed obviously superior. Consequently a request for money adequate to purchase the 6600 was submitted to the National Science Foundation in the budget for Fiscal Year 1965. The money was not granted for the year requested although the response was far from discouraging. One of the suggestions which came out of the discussions of the Panel on Atmospheric Sciences of the President's Science Advisory Committee, which reviewed NCAR's budget and computing needs, was the establishment of the computing group as a national facility. NCAR is now in the process of establishing such a facility and in the coming year will do everything in its power to encourage outside usage of the machine.

Dr. Gary has been working on the application of finite difference techniques to linearized hydrodynamic stability problems. This requires the computation of eigenvalues and eigenvectors of large complex matrices. For example, it is hoped that this method can be applied to atmospheric stability problems which are "both barotropic and baroclinic" and to boundary layer instability such as the Blasius flow and the Eckman layer. It is hoped that one code can be written which will solve these diverse problems with a minimum of modification.

Atmospheric Chemistry

James P. Lodge, Jr.

Group Members

Staff expansion continued at a much reduced rate during calendar year 1963. New personnel were either technicians in support of research personnel or were part of our service functions -- analytical services and the operation of the mass spectrometer at the University of Colorado. One additional laboratory was added to house the research on the Piccardi effect.

Past Work

Work on the improved carbon dioxide meter mentioned in the 1962 report was halted when the instrument specialist left the group. It is now hoped that this work will be finished within the current fiscal year by contracting for the necessary electronic work.

The report for 1962 also mentioned a method for the determination of formaldehyde associated with airborne particulate matter. Little additional work was done on this technique since it was felt that it was insufficiently sensitive to measure the amounts of formaldehyde anticipated in individual particles. However, a number of tests were run in the Los Angeles smog, and it was found that the sensitivity of the test was entirely adequate. Smog particles are apparently associated with amounts of formaldehyde as large as several picograms.

Studies made at Yellowstone Park during the early part of 1963, and subsequently followed up in Boulder, indicated that the Millipore filter technique for determining freezing nuclei could be used to distinguish whether snow was formed on natural or artificial nuclei. When the snow was collected on the filter and the sample carefully warmed so as to sublime the water away, snow formed on natural nuclei yielded no residue capable of nucleating the re-formation of ice at $-15^{o}C$. Crystals nucleated on silver iodide, however, under the same treatment yielded a quantitative recovery of the nuclei with subsequent regrowth of ice around them. This further suggests the possibility of a membrane filter analog of the Isono technique applicable to bulk samples of rain water. A paper reporting the work on snow crystals was presented at the International Conference on Condensation and Freezing Nuclei at Clermont-Ferrand, France in April, 1963.

The continuation of studies of sulfur dioxide collection by impregnated membrane filters showed that, although the gas was retained quantitatively, it could not be recovered from the filters. Consequently, work was shifted to the use of glass fiber filters as the support for the chemical impregnant. A system was developed which was capable of retaining more than 95 per cent of the trace sulfur dioxide, and from which the material could be recovered as sulfite. Meanwhile, work on the detection of particulate sulfate was completed, and the paper reporting this work has been published. Several applications of the technique have been made, with uniformly high success.

A study has been completed which has elucidated the mechanism, and the reaction products, in the Schiff reaction as it is applied to the determination of sulfur dioxide. A further inference to be drawn from the results of this study is that it may be possible greatly to increase the sensitivity of the chemical method by appropriate selection of the solvent medium in which the reaction is carried out. A paper on this subject has been accepted by Analytical Chemistry.

The study of organic freezing nuclei is now virtually complete. A paper is in the late stages of preparation for publication and will probably be offered to the Journal of Atmospheric Science. The important outcome of this work is the discovery that a well-known physical property of substituent groups in certain aromatic compounds, the Hammett sigma function, is a predictor of very high accuracy for both onset temperature of freezing and for relative activity at a given temperature below the nucleation point.

The technique for ozone proved to be as specific as we had hoped. A paper on the subject was presented at the September, 1963, meeting of the American Chemical Society and has been published in Analytical Chemistry.

With the visit during the summer of 1963 by Drs. Stephen V. Filseth (Harvey Mudd College) and James N. Pitts (University of California at Riverside), we initiated an investigation of the photochemistry of certain terpenes. This work is in support of the hypothesis by Dr. Frits Went (St. Louis Botanical Garden) that many natural hazes may result from a reaction similar to that of the Los Angeles smog, but involving hydrocarbons of biological origin. It has been found that the problem is almost unbelievably complex. The photolysis of pure α-terpenine in the absence of oxygen at 2537A produces no fewer than 40 products. These are readily separated and determined by vapor phase chromatography, but their identification presents a formidable problem in itself. However, work is in progress to use the mass spectrometer for this purpose.

The study of air pollution in Denver has reached its mid-point. Data from the first year were judged insufficient to warrant a technical publication, but they were a subject of a release made to the press, to interested public groups, and to the public health agencies of the state, county, and city. Work is continuing further to delineate the precise nature of the pollution complex in the Denver area.

The electron microscope was put to work on a problem of the morphological identification of sulfuric acid drops and of phosphate particles. Both of these were successful, the former representing an adaptation of a method developed in England, and the latter being completely new work. Both species have been found to be present in the Los Angeles smog, and a sufficient number of phosphate particles have been found in marine aerosol collected over the Pacific Ocean to suggest phosphates as the most probable explanation of the "slick patches" which are characteristic of the Continental Shelf areas of the oceans.

Studies of the Piccardi effect have convinced the research group that this effect actually exists. Available manpower has been insufficient to collect long runs of data in simple repetition of Piccardi's own measurements. We have concentrated instead on studies to elucidate the nature of the effect and to find more sensitive measures of its magnitude. In many cases, the effect is so small that it can be detected only by statistical techniques from very large samples of data. However, there is every indication that at last we have found what we are looking for. The particle mobility of freshly precipitated bismuth oxychloride is extremely sensitive to the electromagnetic environment. A 20 per cent difference was produced by treating the water in which the precipitation was carried out with a scale buoy.

Present Work

A group of our techniques for the identification of substances present in particulate matter, including sulfate, phosphate, chloride, and formaldehyde, are being applied to the studies of the chemistry of the marine atmosphere. Two field trips have been made, and a third is projected, with the specific intent of studying gradients in the lowest 15 meters over the ocean surface as a function of wind speed (and thus of austausch coefficient).

A group of techniques and tools are being developed for a projected study of the impact of vulcanism on the chemistry of the atmosphere. A large demountable tower and boom were designed and built at NCAR, intended for use in the sampling of gases from volcanic vent holes which cannot be approached more closely than 75-100 ft because of high temperatures, toxic gases, or other hazards to personnel. Corresponding analytical techniques are progressing well, and are, in part, reported elsewhere in this document. The basic equipment was tested in Yellowstone Park in January, 1964, using one of the geysers as a model of the hazards of an active volcano. The tests were entirely satisfactory. A device for obtaining aerosol samples from aircraft is presently in development under contract. It is planned to make the initial full-scale experiments on the Hawaiian volcano since these are generally less hazardous than those of some other parts of the world. Consequently, as these devices are perfected, they will be shipped to Hilo for storage until they are needed.

An application has been made for support through a grant from the National Institutes of Health of the work on collection on impregnated filters. Our present knowledge of the collection of sulfur dioxide has two major gaps: first, we do not know the effect of widely varying temperatures on the process, and second, we have not yet attempted to work with extremely high concentrations of sulfur dioxide. Furthermore, little work has been done on substances other than sulfur dioxide. The volcano sampling program alone requires the ability to test for numerous additional substances, and at extremes of temperature and concentration. Some equipment has already been developed and a program of testing will shortly be initiated. We can proceed much more rapidly with additional support, however.

Some loose ends remain to be investigated in the study of the new technique for ozone. These have been put aside momentarily due to the pressure of other work, but they will probably be resumed in the near future. Specifically, it will be necessary to show that the two ozonolysis products, anisaldehyde and anisic acid, are formed in exactly equivalent amounts. Some further investigation also will be necessary of the report from Dr. Cadle's laboratory that hydrogen sulfide interferes with the reaction. The mechanism of such interference is not clear, and it should be investigated before a final report on the technique is made.

The work on terpene photochemistry is continuing at a gratifying rate, with continuing assistance from Pitts and Filseth through correspondence and occasional telephone conversations. Although it is scarcely to be hoped that all products will be identified within a year, enough valid data should be ready to warrant a paper at the September, 1964, meeting of the American Chemical Society.

In the electron microscopic identification of phosphates, one complication has recently risen. It has been shown that a number of carbohydrates yield appearances superficially similar to the phosphates. This was not unanticipated, but it is nonetheless disconcerting. However, possible techniques for averting this interference have been suggested and are presently under study. Meanwhile, through collaboration with Professor A. Goetz, it has been found that the organic matter associated with virtually all particulate collections, whether maritime, continental, or urban, can be removed by careful washing with chloroform or ether. This technique will be utilized during the projected marine sampling expedition to distinguish between the organic and inorganic components of the aerosol.

Equipment is virtually complete for the study of the Piccardi effect on electrolytic conductivity. Plans have also been made for the precise determination of the spectrum of emitted electromagnetic energy from the scale buoy. The available literature has been searched and, for the first time, we have a fair idea of the total energy of the electromagnetic environment in earth's atmosphere. A paper on this subject will be presented shortly at a scientific meeting. We have demonstrated a substantial Piccardi effect on the viscosity of water, and we are also presently studying the effect of the scale buoy upon the spontaneous ice nucleation temperature of water, together with its effect on susceptibility to the initiation of freezing by shock waves. This work is being done in collaboration with Dr. Goyer's group.

Personnel are on hand, and most of the equipment purchased, for the laboratory which is to assume responsibility for the U.S. Precipitation Analysis Network. As soon as the laboratory in the new building is completed, we will begin running split samples with the Cincinnati group now doing the analysis. With the start of FY 1965, we will bear full responsibility for these analyses. Expansion of the group to perform other analytical services will be entirely determined by available funds.

Future Plans

A number of possible areas of research and collaboration will be explored. These include specifically the possible establishment of a marine environment station at the projected marine field station at the University of Southern California at Catalina Island, a series of balloon flights by instruments capable of determining stratospheric concentration of hydrogen sulfide and sulfur dioxide, and the initiation by the Analytical Services group of a routine program of atmospheric monitoring for a number of gases of geochemical interest, including methane, carbon dioxide, carbon monoxide, and the sulfur gases.

Publications in 1963

Barber, Ethel D. and James P. Lodge, Jr.: "Paper chromatographic identification of carbonyl compounds as their 2,4-dinitrophenylhydrazones in automobile exhaust," Analytical Chemistry, 35, 348-350, 1963.

Lodge, James P., Jr.: Book review of ASTM Standards on Methods of Atmospheric Sampling and Analysis, Bulletin of the American Meteorological Society, 44, 740, November, 1963.

Lodge, James P., Jr. et al.: "Methods of analysis of polluted atmospheres in the U.S.," Air and Water Pollution, An International Journal, 7, 79-90, 1963. ALSO in shortened version in Gigentia I Sanitarya, 9, 75-78, 1963.

Lodge, James P., Jr. and Joshua Z. Holland: "Atmospheric chemistry," Transactions of the American Geophysical Union, 44, #2, 365-369, 1963.

Lodge, James P., Jr., John B. Pate and Helen A. Huitt: "Filling hypodermic syringes from gas cylinders," Chemist-Analyst, 52, 53, 1963.

Lodge, James P., Jr. and K. J. Parbhakar: "An improved method for the detection and estimation of micron-sized sulfate particles," Analytica Chimica Acta, 29, 372-374, 1963.

Lodge, James P., Jr., John B. Pate, and Loren W. Crow: "A special study of air pollution in the Denver metropolitan area," mailed to news media.

Lodge, James P., Jr., John B. Pate and Helen A. Huitt: "The use of impregnated filters to collect traces of gases in the atmosphere. I. Suitability of membrane filters," American Industrial Hygiene Association Journal, 24, 380-387, 1963.

Lodge, James P., Jr., Charles Xinteras, John B. Pate, et al.: "Methods of analysis of polluted atmospheres in the U.S.," Air and Water Pollution, An International Journal, 7, #2/3, 79-90, May, 1963.

Pate, John B. and James P. Lodge, Jr.: "Rack for square cuvettes," Applied Spectroscopy, 17, #3, 76, 1963.

Pate, John B., James P. Lodge, Jr., and Michael Neary: "The use of impregnated filters to collect traces of gases in the atmosphere. II. Collection of sulfur dioxide on membrane filters," Analytica Chimica Acta, 28, 341-348, 1963.

Papers Presented in 1963

Bravo, Humberto A. and James P. Lodge, Jr.: "Specific spectrophotometric determination of ozone in the atmosphere," presented at Fall ACS meeting, September, 1963, in New York. Also submitted to Analytical Chemistry and will be published in an early issue.

Huitt, Helen A. and James P. Lodge, Jr.: "Solvent effects on the determination of sulfur dioxide with pararosaniline and formaldehyde," presented at 145th ACS meeting, New York, September, 1963.

Lodge, James P., Jr. and Evelyn R. Frank: "Characterization by metal-shadowing of droplets and particles collected on silicon monoxide coated films," presented at 145th ACS meeting in New York, September, 1963.

Pate, John B., James P. Lodge, Jr. and Loren W. Crow: "A preliminary report on Denver air pollution study," presented at annual meeting of Rocky Mountain Section of American Industrial Hygiene Association in Albuquerque, October, 1963.

Isotope Geophysics

Edward A. Martell

Group Members

The present staff of the isotope geophysics group includes: E. A. Martell, nuclear chemist; A. E. Bainbridge, nuclear physicist; J. P. Shedlovsky, nuclear chemist; E. H. Denton, instrument engineer; C. A. Watkins, chemist; Barbara Stafford, chemist; Judith Loraas, chemist; R. A. Leub, electronics technician; and Janet Smith, secretary.

Progress has been made in the development of research facilities. Three laboratory rooms (approx. 1800 sq ft) have been furnished, supplied and equipped for radiochemistry, high vacuum work, instrumentation and low-level counting. Instrumentation for low-level gas counting of tritium and carbon-14, for low-level solid beta measurements, for X-ray and gamma ray spectroscopy, and for cosmic-ray neutron flux measurements are in use. Vacuum lines for processing tritium samples and for separating the CH_4 and H_2 fractions of large air samples have been constructed.

Program Description

An isotope physics and chemistry research group has been established within the Laboratory of Atmospheric Sciences, NCAR, with Martell, Bainbridge, and Shedlovsky as principal investigators. The general scope of the experimental research program is as follows:

a.) Investigation of distribution and reactions of trace gases in the atmosphere will be carried out using methods of stable and radioisotope analysis. These studies will be concerned primarily with the isotopic geochemistry of hydrogen, oxygen and carbon, including investigation of H_2, CH_4, H_2O, and CO_2 in particular.

b.) Studies of trace radioactive and inert aerosols of the atmosphere will be conducted by neutron activation and radioisotope analysis methods. Investigations will include selected studies of fallout, natural radioactivity, micrometeorites, and the composition and origin of stratospheric aerosols.

c.) Emphasis will be placed on upper atmosphere studies by laboratory analysis of aerosol and gas samples collected by aircraft, balloon, and rocket-borne sampling systems. This work will be supplemented by laboratory investigation of gas reactions and by selected studies of the surface air distribution of trace gases and their exchange with the biosphere and surface waters.

d.) Although the objectives of these studies are largely self-evident, emphasis will be placed on the use of aerosol and gas trace distribution for the evaluation of large scale atmospheric transport and mixing processes. The concentration and isotopic composition of water vapor, methane and hydrogen in the upper atmosphere layers will provide insight on features of the water cycle and hydrogen balance of the atmosphere. Distribution of aerosols and gases of common origin will elucidate the role of attachment, growth and sedimentation on aerosol transport. Isotopic analysis of selected constituents of air samples from rocket altitudes should provide direct experimental evidence on diffusive separation processes and on the influx or escape of high atmosphere constituents.

Past Work

Some of the more recent reports and publications by members of the group which bear on various aspects of the research program are listed below (also see 1963 publications and reports, end of text):

Bainbridge, A. E., P. Sandoval and H. E. Suess: "Natural tritium measurements by ethane counting," Science, 134, 552, 1961.

Bainbridge, A. E., H. E. Suess and I. Friedman: "Isotopic composition of atmospheric hydrogen and methane," Nature, 192, 648, 1961.

Bainbridge, A. E., H. E. Suess and H. Wanke: "The tritium content of three stony and one iron meteorite," Geochimica et Cosmochimica Acta, 26, 471, 1962.

Bainbridge, A. E. and B. J. O'Brien: "Levels of tritium in a variety of New Zealand waters," Paper TTS/75, Symposium on the Detection and Use of Tritium in the Physical and Biological Sciences, I.A.E.A., Vienna, May, 1961.

Bainbridge, A. E.: "Tritium in the North Pacific," Conference on Nuclear Geophysics, Woods Hole, May, 1962.

Martell, E. A.: "Atmospheric circulation and deposition of strontium-90 debris," Science, 129, 1197, 1959.

Arnold, J. R. and E. A. Martell: "The circulation of radioactive isotopes," Scientific American, 201, 3, 1959.

Martell, E. A. and P. J. Drevinsky: "Atmospheric transport of artificial radioactivity," Science, 132, 1523, 1960.

Martell, E. A.: "Evidence for high stratosphere holdup of nuclear bomb debris," in Proceedings of the Upper Atmosphere Sampling Symposium, Sandia Corporation Report SCR-420, July, 1961.

Drevinsky, P. J. and E. A. Martell: "Preliminary results on the size and vertical distributions of residual nuclear debris in the stratosphere," in Proceedings of U.S. Atomic Energy Commission Conference on Radioactive Fallout, Germantown, Maryland, November, 1961.

Shedlovsky, J. P.: "Cosmic-ray produced manganese-53 in iron meteorites," Geochimica et Cosmochimica Acta, 21, 156, 1960.

Honda, M., J. P. Shedlovsky and J. R. Arnold: "Radioactive species produced by cosmic rays in iron meteorites," Geochimica et Cosmochimica Acta, 22, 133, 1961.

Shedlovsky, J. P. and G. V. S. Rayudu: "Radionuclide productions in thick iron targets bombarded with 1 and 3 Gev protons," Journal of Geophysical Research, (in press).

Present Work

1.) The first objectives of the experimental program include the determination of the concentration and T/H and D/H ratios of molecular H_2 and CH_4 in tropospheric air samples from clean environments; of H_2, CH_4 and H_2O in stratospheric air samples and possibly of formaldehyde (CH_2O) in precipitation samples. These measurements should contribute significantly to the knowledge of the origin and the atmospheric exchange reactions of these trace gases. For a detailed discussion, see E. A. Martell, J. Geophys. Res., 68, 3759, 1963.

2.) The main experimental problems which must be solved in the early phases of this investigation are the quantitative separation of methane and molecular hydrogen from large air samples without significant trace water contamination. Techniques for collecting, storing, and processing large surface air samples also are being investigated.

3.) Two cryogenic whole-air samplers which will condense 100,000 liters of air in about two hours are being built. These samplers use liquid nitrogen as the cryogen and can be used for air sample collection at surface levels and on large aircraft. The laboratory effort has been placed on development of gas chromatographic techniques for air sample analysis, for determining the distribution and solubility of hydrogen, methane, neon, helium, and other trace constituents of liquid air, and for quantitative recovery of selected constituents.

4.) A program to investigate extra-terrestrial dust in the earth's atmosphere is being set up. Initially samples will be obtained with U-2 aircraft filters at low stratospheric levels. Element and isotope analysis by neutron activation and mass spectrometry will be used to determine the terrestrial and extra-terrestrial components. It is likely that part of this program will be conducted cooperatively with the University of California at San Diego, where mass spectrometric facilities are in existence. Besides the obvious implications of this study, it will augment the program of natural aerosols being undertaken in this group.

5.) Experimental plans have been made to expose compressed air and argon at high mountain altitudes to investigate cosmic ray production rates for tritium and other natural radioactivities. The tank gases will be exposed for about one year beginning in the spring of 1964. In this connection a high-energy proton bombardment of thick targets will be performed at the Argonne National Laboratory in order to simulate cosmic ray effects.

Future Plans

In the future it is planned to extend the investigation of trace gases, aerosols, and radioactivity to upper atmosphere levels using aircraft and rocket sampling systems. A cryogenic rocket sampler which will use liquid or super-critical He or H_2 as cryogen is under development for use at mesosphere and ionosphere levels (over the range of about 40-140 km). Plans and schedules for rocket program are indicated in a recent proposal to NASA.

Papers Presented, 1963

Martell, E. A.: "Radiochemical evidence on stratospheric mixing above 20 kilometers," Upper Atmosphere Meteorology Symposium, I.U.G.G., Berkeley, California, August, 1963.

Martell, E. A.: "Radioactive tracer results on polar stratosphere mixing," and "Radioactive tracer results on equatorial stratosphere mixing," McGill University Seminars on the Stratosphere and Mesosphere and Polar Meteorology, Stanstead College, Stanstead, Canada, July, 1963.

Kaye, J. H., J. P. Shedlovsky, and T. P. Kohman: "Cosmic-ray induced radioactivities in iron meteorites," American Geophysical Union 44th Annual Meeting, Washington, D. C., April, 1963.

Shedlovsky, J. P.: "Depth dependences of radionuclides in meteorites," Gordon Research Conference, Physics and Chemistry of Space, Tilton, New Hampshire, July, 1963.

Shedlovsky, J. P.: "Thick target yields in simulated meteorites," International Conference on the Interactions of High Energy Particles with Complex Nuclei, Leysin, Switzerland, September, 1963.

Papers Published, 1963

Bainbridge, Arnold E.: "Tritium in surface waters of the North Pacific," Nuclear Geophysics -- Nuclear Science Series Report #38 NAS-NRC, p. 129, 1963.

Martell, E. A.: "On the inventory of artificial tritium and its occurrence in atmospheric methane," Journal of Geophysical Research, 68, 3759, July 1, 1963.

Penn, Samuel and E. A. Martell: "An analysis of the radioactive fallout over North America in late September 1961," Journal of Geophysical Research, 68, 4195, July 15, 1963.

Bainbridge, Arnold E.: "Variations of tritium in the North Pacific," Journal of Geophysical Research, 68, 3785, July 1, 1963.

Shedlovsky, Julian P. and James H. Kaye: "Radioactive nuclides produced by cosmic rays in Sputnik 4," Journal of Geophysical Research, 68, 5069, September 1, 1963.

Plasma Physics (Magnetohydrodynamics)

Yoshinari Nakagawa

Group Members

Y. Nakagawa, Ph.D.	Program Scientist
L. R. West, B.S.	Student Assistant
N. J. Sliski, B.S.	Student Assistant

Introduction

The Plasma Physics program has been organized to attain the basic knowledge concerning hydromagnetic phenomena of specific interest in astrophysics and geophysics. The program consists of three major experimental and two major theoretical programs at present and these programs are designed in cooperation with the other research programs at HAO, particularly the Vacuum Spectroscopy program.

The experimental programs are:

1. Study of the structure of shock under non-LTE conditions.
2. Study of the boundary between a plasma and a magnetic field (a model experiment of the magnetopause).
3. Study of the effect of magnetic compression on a plasma and its radiation (a model experiment on the mechanism of the onset of solar flare).

The theoretical programs are:

1. Numerical computations of the time-dependent spectral line intensities and macroscopic physical quantities in the shock transition layer under non-LTE conditions.
2. Study of stellar magnetism and the formation of sunspots.

No experiment has been performed since, until recently, there has been no laboratory space available for the program. In the meantime, a series of seminars on plasma physics has been organized. These seminars are designed to educate students, and to promote future cooperation among different institutions. Personnel from HAO, JILA (Joint Institute for Laboratory Astrophysics), and the Departments of Physics and Aerospace Engineering of Colorado University have actively participated in the seminar program.

Under the program is included the preparation of experiments, namely, the working-out of the details of experimental set up and apparatus, and the ordering of necessary equipment and other utensils.

Present Work

A. Experimental Program

1. Study of the structure of shock under non-LTE conditions. This experiment is designed to obtain basic knowledge on the physical characteristics of the relaxation mechanism behind a strong shock (hydrodynamic as well as hydromagnetic) in rarefied gases. Such a knowledge is instrumental to the understanding of the heating mechanism of solar corona, as well as interstellar gas-dynamics and various phenomena in the upper ionosphere and magnetosphere. No systematic study of such phenomena, particularly under non-LTE conditions, has been made, despite numerous investigations carried out at various institutions. The present research is aimed at accumulating quantitative experimental data so as to provide a basis for the development of systematic theoretical study on such pehnomena.

2. Study of the boundary between a plasma and a magnetic field. The structure of boundary between a plasma and a magnetic field has been one of the major subjects of investigations in the thermonuclear fusion research in connection with the magnetic confinement of the hot plasma. A geophysical example of this type of problem is the "magnetopause," which is formed as the boundary between the impending solar wind and the geomagnetic dipole field. A number of theoretical studies have been developed on the shape of the magnetopause in a static equilibrium, but due to the mathematical as well as physical complexity of the problem, the dynamical characteristics of the magnetopause have never been investigated in detail. This experiment is designed to study the dynamical behavior of such a boundary, including the possible static equilibrium which can be achieved under laboratory conditions.

3. Study of the effect of magnetic compression on a plasma and its radiation. The physical mechanism which leads to the onset of a solar flare is not yet known precisely; however, it is now accepted

that the energy required for the onset of flare is derived from the magnetic energy of the field. On the basis of such an idea, a number of models for the onset of the flares have been proposed. This series of experiments is designed to examine the physical principles of these different proposed models and test their validities through observations, particularly of the shape of the spectral lines and its dependence on the macroscopic physical characteristics.

In all experiments, an electric-discharge-shock-tube type of apparatus will be used to produce the plasma, and as the major diagnostic tool, a time-resolved spectroscopy will be employed together with other techniques, such as streak- and image-converter camera photography, electric or magnetic probes, and microwave diagnostics.

B. Theoretical Program

1. Numerical computations of the time-dependent spectral line intensities and macroscopic physical quantities under non-LTE conditions. A non-LTE computational scheme to evaluate the time-dependent spectral line intensities for a given set of electron density and temperature has been developed at HAO (Vacuum Spectroscopy). However, in order to interpret the data of the proposed experiments, it is necessary to develop a scheme more realistic to the experimental circumstances. This study is designed therefore to develop such a scheme of computation, including the couplings between the existing non-LTE scheme and the macroscopic equations which govern the physical quantities, such as density, temperature and velocities of flow of electrons, ions, and neutrals.

2. Study of stellar magnetism and the formation of sunspots. It has been shown that a star under rotation having a convection zone can develop a toroidal magnetic field. It is then reasonable to consider that in a star like the sun, with its convection zone near the surface, the coupling of such a magnetic field with the finite amplitude convective flow (a jet stream type of flow) may lead to the development of sunspots. The proposed study aims for systematic theoretical investigations of the stellar magnetism in general and the examination of the

possibility of the formation of sunspots through the dynamical mechanism described above.

Future Work

A. Experimental Program

Upon completion of the laboratory the experimental program No. 1 will be undertaken. It is estimated that it will take a few months to a year before the apparatus can be brought into operation and reliable experimental data can be obtained. Experimental program No. 2 will be prepared depending upon the progress made on the program No. 1 and upon space and the availability of personnel. The program No. 3 will be considered as the successive developments of programs No. 1 and No. 2 are brought into operation after 1965.

B. Theoretical Program

Theoretical program No. 1 will be developed immediately so that the tentative theoretical results will be available for the interpretation of the experiment No. 1. For theoretical program No. 2, basic studies needed for the formation of the problem will be undertaken; also an analytical approach to the problem will be explored.

Publications for 1963

(Work done at the Joint Institute for Laboratory Astrophysics.)

Nakagawa, Yoshinari and K. B. Earnshaw: "Experiments on self ionized shock waves in a magnetic field," The Proceedings of VI International Conference on Ionization Phenomena in Gases, Paris, 1963.

Synoptic Meteorology

Chester W. Newton

Group Members

The Synoptic Meteorology group was initiated in July, 1963. Its members are Chester W. Newton (joined July 1, 1963), Henry M. E. van de Boogaard (July 20, 1963), Harry van Loon (July 1, 1963), and Yukio Omoto (August 1, 1963, visitor for one year). In addition James C. Fankhauser (August 1, 1963) is assigned to NCAR by the U. S. Weather Bureau for a year.

Present Work and Plans

Most of the present work is in continuation of diverse projects or interests brought with them by the individuals.

Newton has extended the work in an earlier paper (Journal of Meteorology, 1959, pp. 638-645), to define the properties of "partial inertial oscillations" in the atmosphere. The basic notion is that, in the region of the jet stream, the changes of velocity undergone by an air particle are directly proportional to the changes of the vector geostrophic wind. This hypothesis prescribes certain geometric characteristics and dimensions of the waves associated with wind-speed variations along the jet stream. Certain favored dimensions have been identified (oscillations with a period of a full pendulum day). Further investigation will be made of the interaction between these "inertial" waves and the Bjerknes-Rossby "planetary" waves which have different characteristics. This work will be reported at the Washington meeting of the American Meteorological Society in April, 1964, and will be submitted for publication under the title "Properties of partial inertial oscillations in the atmosphere, with particular application to waves in the jet-stream region."

Newton has also revised an article based on analyses mainly carried out elsewhere, which is being sent to the Journal of Applied Meteorology under the title "Subtropical front and jet-stream variations during interaction with an outbreak of deep polar air." This is a description of the unusual atmospheric structure observed when polar air moves southward beneath the subtropical jet stream, and of the very different thermal and kinematic structures observed at various locations along this current.

Van de Boogaard has continued a detailed study of the energy budget of the atmosphere between the Equator and 40°N for December 12, 1957. A thorough analysis of the three-dimensional wind, geopotential and temperature has been made and the budgets of angular momentum, kinetic energy, water vapor and total energy computed for a steady state. The results show that mean meridional circulations exist, and that these circulations play the dominant role in the equatorial latitudes. In subtropical latitudes, meridional and eddy circulations play an equal role. Portions of this work were reported at the WMO Symposium on Tropical Meteorology in Rotorua, New Zealand, on November 5-13, 1963, in a lecture entitled "On the distributions in the meridional plane of some physical properties of the atmosphere between the Equator and 40°N, based on a single day's data."

The exhaustive length of time it took to analyze the tropics on a single day to global extent prevented the extension of the study for more than one day. However, since his contact, at Rotorua, with tropical meteorologists from other parts of the world, van de Boogaard is convinced that the analysis of the tropical synoptic weather map on a global scale on a routine basis is feasible. Furthermore, he is convinced that satellite cloud and radiation data form an indispensable source of data for tropical analysis. If present efforts to improve the exchange of data and analysis from tropical countries succeed, the above study will be continued. At the same time it is hoped that the feasibility of routine daily tropical synoptic maps on a global scale will be demonstrated.

Future work planned by van de Boogaard includes an analysis of the circulations and budgets of the various types of energies over the continent of Africa. Data used will be that of the second year of the IGY. The tropical circulations, despite their great influence on higher as well as low-latitude meteorological processes, represent one of the great areas of ignorance. Over Africa, during the IGY, there was a relative abundance of upper-air observations, which make it possible to define these circulations both north and south of the equator, and to gain some insight into their physical nature.

H. van Loon, while in South Africa, was largely responsible for analysis of the Southern Hemisphere Daily Sea-Level and 500-Millibar Charts, for the IGY period. The analysis methods used in this generally data-sparse hemisphere have been described in a paper entitled "Southern Hemisphere weather maps for the International Geophysical Year." This paper, co-authored with J. J. Taljaard of the South African Meteorological Service, is in press for the Bulletin of the American Meteorological Society.

A logical extension of the daily analysis work has been a study of the characteristics of the mean flow patterns of the Southern Hemisphere. The results are to be reported in a talk at the Washington AMS Meetings in April, 1964, and will be submitted for publication under the title "Mid-season average zonal wind at sea level and 500 mb south of 25°S, and a brief comparison with the Northern Hemisphere." Among the facts brought out by this analysis is that, although the mean upper-air flow appears to be nearly zonal, there is in reality a pronounced asymmetry in the circulation during the colder part of the year. The circulation and its seasonal changes are shown to be related in a strikingly direct way to the surface temperature distribution. Although on the whole there is a strong control arising from the oceanic dominance of the hemisphere, there are, particularly in the Australasian sector, large disturbances connected with continental influences on heating or cooling. These influences appear to be responsible for the circulation asymmetry mentioned earlier. The Australia-New Zealand region is one in which "blocking" of the westerlies frequently occurs, and this phenomenon will be studied both there and, for purposes of comparison, in the Northern Hemisphere.

Omoto, jointly with Newton, has carried out a study of trajectories in an isentropic surface near the jet stream. On theoretical grounds, air particles should not have any appreciable movement across the jet-stream axis, and one objective is to establish whether this is so. Kinematic and energetic requirements dictate, under such conditions, that the jet stream in a moving wave should have a larger amplitude of meander than the streamlines, in agreement with observations.

Fankhauser is carrying out a complete analysis of a squall-line situation on May 28, 1962, with the objective of computing the budget of water vapor, the divergence and vertical motion field, and so on. In collaboration with Newton, he is continuing a study begun at the National Severe Storms Project, Kansas City, on the movement and development of thunderstorms. The principal finding is that, under typical conditions wherein the wind veers with height, large storms move appreciably to the right, and small storms to the left, of the vector mean wind in the cloud layer. Results will be reported by Newton at the National Conference on the Physics and Dynamics of Clouds in Chicago in March, 1964, under the title "Thunderstorm movements relative to upper winds, for storms of different sizes."

In the summer of 1964, it is expected that Professor E. Palmen, Academy of Finland, will visit NCAR to work with Newton on a monograph on Synoptic Aerology. It is also expected that Dr. Roy Berggren, Swedish Meteorological and Hydrological Institute, will visit NCAR to perform synoptic analyses in connection with ozone measurements.

Aerocolloidal Systems

Jan Rosinski

Group Members

The staff in the group consists of the following persons: Mr. Jan Rosinski, Mr. Takeshi Nagamoto, Mr. Gerhard Langer, and Mr. John M. Pierrard. In addition to the permanent staff, a group of three high school students worked during summer vacation. High school students from different geographical areas are appointed for two years to work with the group.

Past and Present Work

Some apparatus for experimentation with liquid/gas and solid/gas dispersions has been obtained. Specialized equipment was designed and built by NCAR shop facilities.

Experiments in the field of particle deposition on (or particle capture by) raindrops, snowflakes, and coniferous trees are being continued. Experiments with spheroids are intended to establish particle trajectories to provide the basis for calculations of capture efficiencies, by raindrops. Experiments with coniferous trees should uncover the mechanism of particle re-entrainment and also should give correction for deposition of particles during diffusion of an aerosol cloud traveling through a forest. Preparations were completed for studies of size classification of particles in an electrostatic field and for design of an acoustical particle counter.

Theoretical work on the secondary particles hypothesis is being continued. The possibility of finding a connection between the occurrence of meteor storms or very low meteor shower activity and corresponding rainfall anomaly is being investigated.

Preparations were started for the field test program to study scavenging of particles by snow crystals. This test is being planned for the year 1967.

Papers published in 1963:

A. From Previous Work

Bitten, J., and J. Rosinski: "Disintegration of pellets in ocean water," Kolloid-Zeitschrift, 190, 115-123, 1963.

Langer, G.: "Where alertness 'counted' (acoustical particle counter)," Research/Development, 6, 40-2, 1963.

Langer, G., and J.M. Pierrard: "Anomalous behavior of aerosol produced by atomization of monodisperse polystyrene latex," Journal of Colloid Science, 18, 95-7, 1963.

Langer, G., J. Rosinski, and S. Bernsen: "Organic crystal as icing nuclei," Journal of Atmospheric Science, 20, 557-562, 1963.

Pierrard, J.M.: "Capture of hydrophilic and hydrophobic particles by condensing and evaporating water droplets, Part II, Theory and analysis of experiments," Kolloid-Zeitschrift, 190, 129-135, 1963.

Rosinski, J., J. Stockham, and J. Pierrard: Capture of hydrophilic and hydrophobic particles by condensing and evaporating water droplets, Part I, Experimental study," Kolloid-Zeitschrift, 190, 126-129, 1963.

B. From Present Work

Rosinski, J., J.M. Pierrard, and C.T. Nagamoto: "Particle trajectories and capture of particles by a sphere," Kolloid-Zeitschrift, 192, 101-6, 1963.

Atmospheric Electricity

J. Doyne Sartor

Group Members

J. Doyne Sartor	Program Scientist	August 1962
Jack D. Tefft	Program Engineer	October 1962
Alan H. Miller	Research Scientist	November 1962
Michael G. Wilkins	Research Scientist	June 1963
Paul A. Eden	Technician	May 1963
Lawrence McElhaney, Jr.	Technician	October 1963
Joy Coombs	Technical Secretary	June 1963

Jack Miller of Computer Services is assigned to this research program for computer programming, and Kanwal Parbhakar is working on the model experiment.

General Statement of the Research Program

The first major object of this research program is to determine the interrelationships between particle interaction and the electrification of clouds. During the past year the methods of investigation have tended to turn more and more towards the study of the electromagnetic emission from these clouds and what this emission means in terms of cloud growth parameters. A second major portion of the program is concerned with extra-terrestrial effects on the electric field and in turn the role that the electric field of the atmosphere plays on the initiation of electrification in clouds. The research problems are being approached theoretically, in the laboratory and by field study in such a way that each of the phases of the program complement each other at all stages of progress.

Past Work, Results and Conclusions

At the present time, the role of the electric field in the initiation and growth of precipitation is being approached largely by theoretical methods. The collision efficiencies obtained when the electric field is added to the normal motion of interacting cloud drops are being compared with the purely hydrodynamic collision efficiencies. The inverse problem, that of the interaction of particles in an electric field in a manner that enhances the electric field, is being studied, also through theoretical and computer techniques.

The growth of precipitation and the growth of cloud electrification is being investigated indirectly in the field by studying the electromagnetic emission from early stages of growth of clouds. At the present time this study has been limited to the radio emission from warm clouds. A two-week field program was conducted in Key West, Florida, in the summer of 1963, resulting in positive identification of radio signals from warm clouds with temperatures entirely above zero degrees centigrade. Since this emission occurred in discrete bursts, this finding from warm clouds puts a new complexion on the entire problem of cloud electrification, especially in the absence of the ice phase.

Complementing the field studies in radio emission from clouds are the studies in the laboratory of the radio signals from the collision between individual pairs of charged droplets and uncharged droplets in an electric field. During the past year we were able to positively identify radio signals from the collision between charged water drops. These radio signals appeared in the same frequency region as the radio signals observed in the field studies. No direct relationship between the two has been established yet.

Because of the interest of the Atmospheric Electricity Committee for the IQSY and because of invitations to place our instruments at high altitude locations, we have proceeded faster than we had anticipated with the installation of electric field meters for measuring the high altitude fields and radio receivers for obtaining the radio emission from blowing snow. Cooperative studies have been initiated at Chalk Mountain near Climax, with Colorado State University, and with the Arctic and Alpine Research Institute of the University of Colorado, on Niwot Ridge. These studies did not get started early enough this winter to avoid the hampering snow and cold-weather conditions of the high altitudes. However, in spite of the snow and cold we expect to have operating instruments at both locations before the end of the season.

Reports of the results of the research conducted during this year, and previously, were made at the Third International Conference on Atmospheric Electricity, Montreaux, Switzerland, as part of a discussion of the theory to explain the electrification of clouds. A paper discussing the relative roles of thunderstorm was also presented at the Berkeley meetings of the International Union of Geodesy and Geophysics during the latter part of August. A paper presenting the laboratory results and theory behind the study of the radio emission from clouds was published in September 1963 in the Journal of Geophysical Research, vol. 68, no. 18. A second paper has been accepted for publication by Science, on the results of the summer field project at Key West.

Present Work and Immediate Plans

The theoretical calculations of electrostatic collision efficiencies and growth of electric field proceed very slowly and will be continued next year, with the hope that we will be able to get out a small catalog of electrostatic collision efficiencies based on the best approximations to the solution both from the hydrodynamic and electrostatic standpoints. We intend to have at least two instruments operating at both the Chalk Mountain (Climax) and Niwot Ridge high altitude stations. The problem at Niwot is power, since the only way that we can get power there now is with a wind generator. The fierceness of the wind has caused considerable delay by promptly blowing down each wind wheel shortly after its erection. We hope an airplane propeller will solve this problem. Before the year is over we have hopes of being able to get a radar in operation in conjunction with the measurements at Niwot Ridge and for the Key West field project this summer.

Laboratory studies will be emphasized as much as we can during the period between now and the middle of the year, when our field project will start. In these laboratory studies we hope to be able to investigate the power spectrum of the radio emission from colliding drops. This will be done in at least two different ways: through colliding streams of droplets which collide in pairs, and through the use of our vertical wind tunnel, in which we can study the interaction of clouds of electrified droplets or the radio emission from cloud droplets which have been excited suddenly by high field.

We now have a large tank filled with mineral oil in which we can produce drops which have the same Reynolds number as cloud drops, and although an exact simulation cannot be obtained in these model experiments, we plan to check some of the hydrodynamic theory involved in them and to use the model experiments as a source of ideas concerning the interaction of drops.

Papers Published, 1963

Sartor, J. Doyne: "Comments on paper by N. R. Lindblad and R. G. Semonin, Collision efficiency of cloud droplets in electric fields," Journal of Geophysical Research, vol. 68, no. 15, p 4632, 1963.

Sartor, J. Doyne: "Radio emission from clouds," Journal of Geophysical Research, vol. 68, no. 18, pp 5169-5172, 1963.

Sartor, J. Doyne: "Thunderstorm electricity; comments on the paper by M. Brook, B. J. Mason and B. Vonnegut," Proceedings of the Third International Conference on Atmospheric and Space Electricity, Montreaux, Switzerland, 1963.

Papers Presented, 1963

Sartor, J. Doyne: "Microwave emission from clouds," at the AMS-AGU meetings in Washington, D.C., April 17, 1963.

Sartor, J. Doyne: "Thunderstorm electricity; comments on the paper by M. Brook, B. J. Mason and B. Vonnegut," at the Third International Conference on Atmospheric and Space Electricity, Montreaux, Switzerland, May 7, 1963.

Sartor, J. Doyne: "The role of particle interaction in the growth of thunderstorm electricity," at IUGG XIIIth General Assembly, Berkeley, California, August 27, 1963.

Cloud Physics

Patrick Squires

Group Members

Name	Title	Date of Joining
P. Squires	Program Scientist	3/29/62
R. Bushnell	Scientist	9/20/62
V. Glover	Scientist	7/6/62
M. Emmanuel	Scientist	7/16/62
K. Parbhakar	Scientist	7/20/62
W. Booton	Technician	8/30/62
S. Kovacs	Technician	12/10/62
L. Plywaski	Technical Sec'y.	1/16/64

Program

Three areas of work have been continued:

A. Condensation of nuclei

B. Steady state thunderstorm theory

C. Dropsonde program

A. Condensation of nuclei. Progress has been made toward securing reliable measurements of the spectrum of critical supersaturations. Two devices have been brought to a stage where they appear to be usable, and they are being compared. The results to date are encouraging; it seems possible that they will give agreement to about ten per cent, which is rather better accuracy than is needed for the purposes in hand. The fall-out device which was mentioned in last year's report has been been abandoned for the time being because of the sampling difficulties mentioned in that report. These do not, indeed, appear to be insuperable, but it may not prove necessary to follow up this line in view of the good agreement between the two devices mentioned above.

The first of these is the simplest, and one of the earliest forms of the apparatus which was tried. The conclusion mentioned last year that it was impractical to photograph the particles while still falling slowly through the air has been revised, a new photographic technique having greatly improved the results. The doubts which were previously entertained about the accuracy of results obtained in this fashion have been largely removed by the good results of the comparison between this device and a new one developed over the last six months. The new device, unlike the earlier two, which utilize the supersaturation generated between two wet surfaces at slightly different temperatures as a result of the curvature of the saturation-vapor pressure curve, depends on the difference in diffusivity between heat and water vapor. A stream of filtered air passes up a wet-walled vertical tube along which there is a temperature gradient. The stream of air gains both heat and water vapor from the walls of the tube as it moves, but the lag of the central filaments of the stream is larger for heat than for water vapor and this can be arranged to give rise to a supersaturation in the range desired. A thin thread of the air being studied is passed up the center of the tube, and it has proved possible with suitable design to arrange matters so that those nuclei which are activated and grow to form the droplets of cloud drop size eventually fall back through the upcurrent and can be counted as they pass a window through which a beam of light is passing.

In support of the development of these devices, Mrs. Emmanuel has been working with conventional condensation nucleus counters of Aitken and Pollak types. These operate at very large supersaturations, and are not indeed directly relevant to the problem of cloud formation which is our central interest. However when field measurements are undertaken, it will be extremely useful to be able to determine immediately by means of one of these devices whether the sample being taken is representative of uncontaminated air. In addition since there is rich literature concerning measurements of this kind, it will be of some interest to find what correlation if any exists between measurements of the total Aitken nucleus count and the variations in the numbers of particles which are activated at supersaturations of the order of one per cent, and are effective in cloud formation. (Squires, Emmanuel, Booton)

B. Thunderstorm theory. Dr. J. S. Turner, with whom this work was originally undertaken, has withdrawn in view of his other interests at Woods Hole. Relatively little effort has been spent on this work. However it is becoming rather clear that the modification of the profile of the updraft which was envisaged, while interesting and suggestive in connection with the formation of hail, does not affect in any radical way the over-all dynamics of the cloud. Some few calculations have been made of the performance of a plume in the mean Washington sounding for thunderstorm days and for non-thunderstorm days; although the mean soundings differ very little, the theory so far easily distinguishes between them, being consistent with the presence of thunderstorms in the one case and modest cumuli in the other. This apparent agreement with observation may indicate that this simple plume theory includes enough of the important factors to be useful, and it is hoped to slowly proceed with the development of the theory.

C. Dropsonde program. The dropsonde program continued in 1963 with:

1. Evaluation,
2. Design of the system for making measurements,

and 3. Provision of a measurement radar.

1. Evaluation. Our intention is to study thunderstorms by dropping measuring instruments into them. Because of the expense of this sort of undertaking we continued to carefully examine our program as the design of the system progressed. We were helped in this by the visit of Mr. Jack Warner from Australia in July, 1963.

We recognize that of the things it measures, Doppler radar can provide a greater mass of data than can dropsondes. However, Doppler radar has two difficulties: one, side lobes in the antenna pattern make it difficult to resolve reflecting regions of cloud and two, the absence of the small drops in the spectrum of drop sizes leads to some doubt about the vertical speed of the air associated with the reflection received. Doppler measurements give information on vertical air speed and drop size distributions while dropsondes are capable of measuring these and several other things. We take the view that dropsondes will produce better measurements of more things but will yield far fewer cases. We hope that it will eventually be possible to check by means of dropsondes the assumptions which have to be made in interpreting Doppler measurements.

We will use several sondes simultaneously to measure sections of storm cell structure. This is necessary because one sonde cannot give meaningful storm structure data. This choice means that we cannot use any telemeter currently available but must design a lightweight one with a controlled radio frequency. We have considered several properties that might be measured by a dropsonde and have determined to proceed with them in this order:

1. vertical velocity
2. water content
3. horizontal position
4. droplet spectra
5. drop and hailstone impacts
6. icing rate
7. temperature.

(Bushnell, Glover)

2. Design. In November 1963 Automation Industries, Inc. of Boulder, Colorado, completed initial engineering work leading to the design of a dropsonde. This contract will be extended in 1964 to provide sondes for our first measurements. Among other features of the design, they have produced a transistor transmitter of light weight for operation at 400 Mc/s. They have designed a semiconductor strain gage for use with pressure cells such that continuous unambiguous pressure signals can be had without sliding contacts. Their work covered all of the sonde design and part of the ground station design.

Each sonde will consist of a drag body to control the fall speed and an aerodynamic body suitable for pressure measurements and which will contain the radio and transducers. The telemetered signals from the several sondes will be received on the ground and be put on individual channels of a magnetic tape recorder for later analysis. Ground stations will be used rather than airborne stations because the distance to each sonde is to be measured by a transponder technique which requires stations whose positions are known. Although the form of the tracking system was determined this year, to allow early measurements the first sondes to be used will not have tracking circuits. (Bushnell, Glover, Kovacs)

3. Measurement radar. A measurement radar will be used to give a picture of the rain distribution in a storm during the time of sonde measurements. This radar must measure rapidly because the fall time may be as short as five minutes. The radar must give reasonably accurate values of reflectivity, must have good resolution and must have low side lobes.

For this we have chosen to use the 10 cm radar of an M33 system with two major modifications. First, a precision photographic indicator is being made which will give 35 mm photographs of PPI (plan position indicator) and RHI (range height indicator) scans of the storm. This indicator is specially designed for photographing in that it has a single stage phosphor (P11), high contrast optics, corrections for (a)the distance to the storm, (b)distortion by the electron gun in the indicator tube and (c)the divergent sweeps of PPI and RHI displays. It is not usable for visual observation. To insure stability of calibration the indicator has no continuously variable controls (except one azimuth control). When used with a logarithmic IF amplifier, the whole range of received reflectivities is recorded on film. Storm reflectivities will be read from the negatives with a densitometer. This indicator was placed under contract in 1963 with ITT Bell & Gossett, Colorado Research Division, Broomfield, Colorado, for delivery in March 1964.

Second, we are obtaining a pencil beam antenna with low side lobes. During 1963 we searched for a source of such an antenna. The requirement for low side lobes was not easy to satisfy and for practical and economic reasons we have compromised at 30 db down with a 2^{o} beam width. While this puts the side lobe responses down 60 db for round trip transmission, it is barely enough because the range of cloud reflectivities exceeds this by at least 10 db. This antenna will be purchased in 1964. (Bushnell)

Future work

There seems a good prospect that within the next 12 months we will be able to commence field observations of condensation nuclei, beginning with measurements of surface air in the vicinity of Boulder. At a later stage it is hoped to secure samples from lower and middle tropospheric levels by means of aircraft and later still to compare the absorbed concentration of cloud drops in cumuli with that which would be predicted from these measurements.

In 1964 we will receive the first sondes. We will test them by dropping them from a light airplane. We will construct one ground station which we will test with sonde signals. We will do the first complete reduction of sonde data. By late summer we expect to drop sondes into cumulus clouds. After the storm season is over we will return to work on the tracking part of the dropsonde system. We will test the photographic indicator with the M33 radar and use it to measure clouds in connection with the dropping of sondes. We will calibrate the radar to give reflectivity values. We will purchase the pencil beam, low side lobe antenna.

Also during 1964 we will proceed with the design of a water-content meter to be included in later sondes. This will involve the use of a portable wind tunnel to be taken into the mountains where there is an economical supply of cold air.

Dynamical Aspects of Atmospheric Circulation

Philip D. Thompson

In accordance with the intentions stated in the Introduction of the LAS Scientific Report for 1962, NCAR has made a strong effort to build up its competence and broaden its range of interests in the fields of dynamical meteorology and geophysical fluid dynamics. Over the past year, the group concerned with these fields has grown from 5 to 13, including 8 full-time staff and 5 long-term visitors. The full-time staff are: Dr. E. R. Benton, Mr. J. A. Brown, Dr. David Houghton, Dr. Walter Jones, Mr. P. Jordan, Dr. Akira Kasahara, Dr. Philip Thompson, and Dr. Warren Washington. The long-term visitors are: Dr. Günther Fischer, University of Hamburg; Dr. H. Itoo, Japanese Meteorological Agency; Prof. Frank Martin, Naval Postgraduate School; Dr. Fedor Mesinger, University of Belgrade; and Prof. George Platzman, University of Chicago. With the exception of Dr. Itoo, the visitors listed above will have remained at NCAR for a period of one year. In addition to resident staff, Dr. Aksel Wiin-Nielsen has retained his affiliation with NCAR as Research Associate and is actively collaborating with Mr. Brown.

Most of the assistance required by this group is provided by the programming-coding staff of the Applied Mathematics Group, who are also responsible for the operation of the CDC 3600.

The problems currently under study fall into six major categories, namely, the dynamics of large-scale atmospheric motions and the theory of the general circulation, the dynamics of hurricanes, studies of atmospheric acoustic-gravity waves and tidal theory, theory of thermal convection, theory of turbulence, and boundary-layer theory. The remainder of this report is a brief summary of work that has been undertaken or is now under way in these various sub-fields.

Dynamics of Large-Scale Atmospheric Motions

In an effort to describe more completely certain essential features of the atmospheric energy balance, Wiin-Nielsen, Brown, and Miss Margaret Drake have extended their earlier studies of energy exchanges between zonal available potential energy, eddy available potential energy, zonal kinetic energy, and eddy kinetic energy. Data for a two year period have now been completely analyzed and processed, and point to the following main conclusions:

a) A large fraction of the heat and momentum transport during the winter months is carried out by the very long planetary waves.

b) The exchange from zonal to eddy available potential energy shows a marked seasonal variation with maxima during winter and minima during summer. The energy exchanges brought about by the long planetary waves are pronounced during winter.

c) The monthly averages of eddy to zonal kinetic energy exchanges are an order of magnitude smaller than those found for the potential exchange.

Details of these studies may be found in the following publications by Wiin-Nielsen, Brown, and Drake:

1. "On atmospheric energy conversions between the zonal flow and the eddies," Tellus, 15, 1963.
2. "Further studies of energy exchange between the zonal flow and the eddies" (to be published in Tellus).

Related studies by Wiin-Nielsen and Brown, based on computed values of vertical motion, indicate that heat sources and sinks are most intense during the winter. This preliminary result is now being tested with reference to actual conditions over a whole year.

As a preliminary to the design of more complicated and more realistic models of the general circulation, Fischer has devised simple models of the atmosphere and the oceans, coupled by the turbulent exchange of momentum, heat, and moisture across the air-sea interface. The vertical structure of the atmosphere is characterized by four parameters that determine an appropriate polynomial representation; the ocean is simulated by a single homogeneous layer of fluid, acted upon only by the surface wind stress. For simplicity, the zonal distribution of continents and oceans is assumed to be periodic. At the present time, the machine program for solving the relevant dynamical equations is in an advanced state of check-out, and it is planned to carry out a series of numerical experiments over the next few months. Of particular interest is the possibility that the high heat capacity of oceans may induce long-term lag effects on the circulation of the atmosphere.

To give some guide to the design of more complete general circulation experiments, and to aid in interpreting a very large volume of numerical results, Thompson has worked out a statistical formulation of the relevant dynamical and thermodynamical equations, in which the dependent variables are a closed set of statistics that provide a gross physical characterization of the state of the general circulation - e.g. average zonal wind, average potential temperature, net heat and momentum transport and the variances of velocity, vorticity and potential temperature. In this formulation, the only independent variables are geographical latitude and time. The main hypothesis, required in order to form a complete set of statistics, is that the interaction between the average zonal motion and fluctuations on a single predominant scale overshadows the interactions between fluctuations on different scales, a tentative conclusion suggested by the earlier studies of Phillips (M.I.T.), Smagorinsky (U.S.W.B.), and Leith (Lawrence Radiation Labs.). A numerical method for solving the statistical-dynamical equations has been devised by Washington, who will also supervise the programming and coding for the CDC 3600 and will collaborate in the design of suitable numerical experiments.

In conjunction with numerical experiments of the type described above, Washington and Kasahara are proceeding with the design of an extremely general model, in which the physical processes of radiation absorption, radiation emission, scattering and reflection, moisture condensation, evaporation, and turbulent exchange of heat, moisture and momentum are more faithfully reproduced than in the models studied earlier. In formulating suitable methods of computation, they will be guided and assisted by the past work of Fischer, Kasahara, Houghton, and Itoo, who have carried out an extensive investigation of the stability and truncation error of various types of finite difference procedures (including several not discussed by Richtmyer, New York University). A summary of these investigations will appear in a forthcoming NCAR Technical Note.

Dynamics of Hurricanes

It is a widely recognized fact that the maintenance of a mature hurricane depends upon the existence of a continuous supply of water vapor, through evaporation from the underlying sea surface and subsequent transfer aloft. This process has been taken into account in most extant theories of the formation and structure of hurricanes. In virtually all earlier treatments, however, the vertical transfer of moisture was presumed to be horizontally uniform, whereas radar photographs and other more direct observations indicate that most of the vertical transfer is associated with more or less isolated patches of cumulus development. In order to simulate the vertical transfer processes in more realistic fashion, Kasahara has proposed a method of parameterizing the effect of convection in hurricanes, by relating statistical measures of the extent and intensity of convection to various large-scale features of the structure of hurricanes and vice versa. This new aspect of the thermodynamics of hurricanes has now been incorporated in a theoretical model, and a machine calculation of the structure of a typical hurricane is near completion.

Atmospheric Gravity-Acoustic Waves and Tidal Theory

In an extension of his thesis work, Jones has begun a study of the propagation of acoustic and gravity waves under conditions where radiative losses are substantial, a case that has direct application to wave propagation in the solar photosphere and chromosphere. Results to date indicate that most waves of this type are damped in the upper photosphere. Under certain conditions, however, horizontally propagating acoustic waves have very low frequency and correspondingly small temperature fluctuations and small radiative losses. Such waves may be trapped in a thermal duct between the higher temperature of the upper chromosphere and the lower photosphere. The time and length scales of these waves agree well with the observed scales of granular motions. Further refinement of the theory will be checked against observations of solar granulation made by the High Altitude Observatory and the Sacramento Peak Observatory.

Some extensions of his earlier work on surface and internal gravity waves have been undertaken by Houghton, who has attempted to isolate purely non-linear effects on the propagation of gravity waves. His present efforts are directed toward the study of more general effects of non-linearity, including possible non-linear effects in the development of jet streams. Details of Houghton's past work on non-linear effects are included in a paper entitled "A study of non-linear behavior of two-dimensional gravity waves in an inviscid fluid," to be published in the Journal of Atmospheric Sciences.

Thermoconvection

The problem of integrating the Navier-Stokes and heat conduction equations for thermal convection has been approached from two different points of view. Platzman has studied the spectral form of the equations for laminar convection, in which the dependent variables are the amplitudes of the various eigenmodes. In some instances, these equations are subject to exact mathematical analyses but, in any event, can be integrated numerically. Following a different approach, Washington has devised a finite difference scheme for integrating the Navier-Stokes and heat conduction equations in their primitive and complete three-dimensional form. The solution of the general finite-difference form of the equations (which may correspond to either laminar or turbulent flow) is being programed for the CDC 3600.

Theory of Turbulence

Jones has been seeking to extend the Kolmogoroff-Batchelor statistical theory of turbulence to the case of a non-homogeneous medium. If the turbulent fluctuations have suitable time and length scales, he has found it possible to put the equations for turbulent non-homogeneous flow in a form similar to the equations for turbulent homogeneous flow, by a transformation of the vertical coordinate that depends on the static stability. Once the equations are so transformed, dimensional arguments lead to results analogous to those of Kolmogoroff. According to these results, small-scale turbulence should die out at heights of the order of 100 km, a conclusion that is consistent with the observed behavior of sodium vapor clouds. Refinements of this theory will be checked against observations of turbulence spectra, scattering of radio waves, and possibly acoustic scattering.

The statistical methods developed earlier by Thompson in the study of turbulent thermal convection has now been applied to the case of turbulent Couette flow. The main result is an explicit relationship between the Reynolds number and the total transfer of momentum (turbulent + molecular) from one boundary to the other. This result is in agreement with Reichhardt's observations of the average velocity profile in turbulent Couette flow, probably to within experimental error. The fact that the same mathematical technique can apparently be used in dealing with both turbulent convection and turbulent shear flows suggests that it may be possible to treat mixed types of turbulent flow in the same fashion.

Boundary-Layer Theory

Benton has studied the primary and secondary flows arising from the development of a laminar boundary-layer around a rotating sphere. For simplicity, he has supposed that the sphere has started rotating impulsively, and that the surrounding fluid is initially at rest; he then solves the linear form of the boundary-layer equations as an initial value problem and obtains solutions that are ostensibly valid for only small intervals of time after the sphere starts rotating. In the course of this investigation, Benton noticed that a particular type of time-transformation would put the solution into a form similar to that of the non-linear steady-state boundary-layer equations. He has subsequently discovered that this peculiar property is common to the solutions of several other types of boundary-layer problems.

Future Plans

Plans for future work in a number of specific sub-fields are outlined briefly in previous sections of this report. In general, it is our intention to strengthen and integrate our research on various aspects of the general circulation problem and the problem of convection in moisture-laden air. In the first place, a comprehensive treatment of the general circulation problem will require extensive cooperation among groups working in such diverse fields as radiation physics, cloud physics, atmospheric turbulence, and, to some extent, atmospheric chemistry. Thus, the general circulation problem is a natural structure around which the efforts of a laboratory with a wide range of scientific interests and varied ability can be organized effectively. In the same way, any definitive study of the dynamics and microphysics of clouds must start with conscious recognition of the interactions between convective motions in clouds and the microphysical processes of condensation and coalescence and with the buoyancy forces created by the release of latent heat. Accordingly, the simultaneous study of all aspects of convection in a moist atmosphere is another natural means of integrating and directing the efforts of several diverse groups.

Papers Published, 1963

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