**NCAR** Quarterly
Fall-Winter 66/67

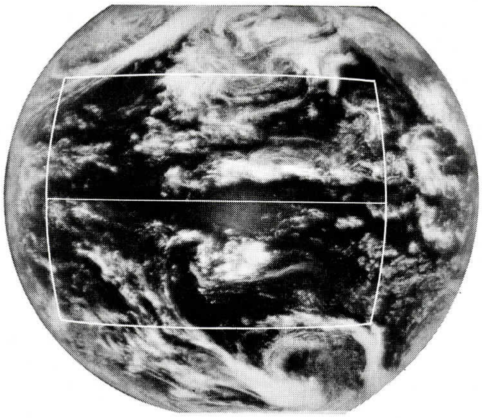
# Experiment in the Tropics

*"... meteorological observations are distributed in obedience to political, social and economic demands and not to scientific prescription. Only a small portion of the troposphere is explored from day to day by our instruments. From this fragment we have to reconstruct in synoptic study, in theoretical deduction or in climatological study the behavior of the whole. Occasionally there are accidents: military necessities suddenly extend the reach of observation; routine observations can be made more accurate by instrumental improvements. In either event the results usually astonish us. The new regions thus opened up for exploration only vaguely resemble those pre-conceived by the theoreticians. It is not only that the griffins and basilisks described by the philosophers are absent; it seems that the country is occupied by creatures of which they have never dreamt."*

*C. E. Palmer, 1952*

Three-quarters of the tropics are ocean surface, and none of the tropical land areas is occupied by a major industrial nation. Most of the world's science, like its business, is conducted in temperate regions. As a result, tropical meteorology has been neglected to the point where our ignorance of this vast area, covering half the earth, has become a serious drawback to the advance of meteorology as a whole. Recently, new opportunities to acquire knowledge of tropical weather processes have led to an ambitious, long-range program to correct this deficiency.

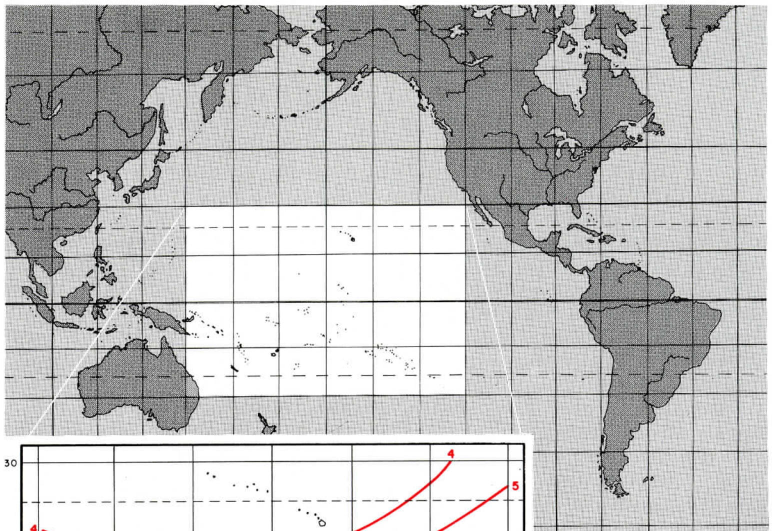
The first step in this program has just been completed. Known as the Line Islands Experiment, it consisted of a series of field observations carried out from February to April, 1967, in and near the Line Islands, in the equatorial Pacific, a thousand miles south of Hawaii. The Experiment was coordinated by NCAR and supported by the National Science Foundation, and involved nearly two dozen government agencies and university and other research groups, who cooperated to secure basic meteorological data from temporary surface and upper air sounding stations, research aircraft, ground-based radar, and shipboard stations. The Experiment was planned to take the fullest possible advantage of photographs from meteorological satellites, especially the ATS-1 synchronous satellite, launched in December 1966, which has been surveying the Pacific Basin from a position nearly over the Line Islands.

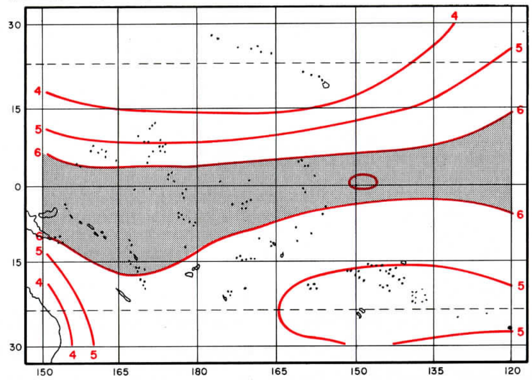


## *A Global Heat Source*

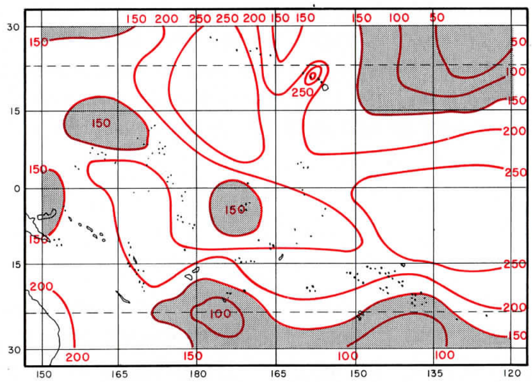
The main importance of the tropics to contemporary meteorology is related to the role of this region in the global circulation of the atmosphere. The tropics receive more heat from the sun than they lose by radiation to space, while over the long run the higher latitudes lose more heat to space than they gain directly from the sun. However, the average annual temperature of the higher latitudes does not diminish over the years; their heat deficit must be replaced from some source. The deficit is, in fact, made up by the transfer of warm air and water vapor from the tropics.

The broad outlines of the circulation from the tropics to higher latitudes were suggested by the English scientist George Hadley in 1735. Hadley pointed out that the effect of solar heating on the equatorial atmosphere is to make the air lighter, causing it to rise and allowing colder air from north and south to move in at low levels. The resulting surface winds flowing toward the equator—the trade winds—are deflected westward in both hemispheres by the earth's rotation (and thereby become "easterly" winds). Hadley noted that the trades must be compensated by return winds aloft, consisting of warm equatorial air, moving poleward and eastward in each hemisphere.

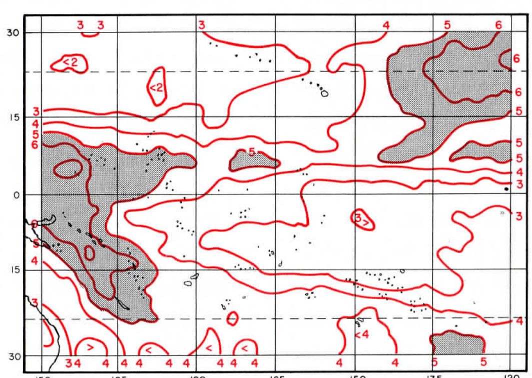




July cloud cover (tenths)



Mean hours of sunshine (July)



July 1965 cloud cover (tenths)

*Advances in the climatology of the central Pacific. The first chart is adapted from Léon Teisserenc de Bort, 1884. The second, from Landsberg's 1937 maps of world climatology, represents a considerable advance in the amount of data presented. The third, prepared in 1966 by James Sadler of the University of Hawaii and NCAR, shows the additional detail made possible by satellite coverage.*

*These charts are not strictly comparable: Teisserenc de Bort presumably summarized information over a number of years to arrive at an average July cloud cover. Landsberg presents mean hours of sunshine in July, an approximate converse of cloud cover. Sadler's chart is based on one month of satellite pictures, July 1965. The ATS satellite picture shows the same region at a single instant.*

Although the trades are among the steadiest winds on earth, within the last 30 years upper air soundings from stations in the tropical oceans have shown that the return "anti-trades" are by no means as steady or predictable. The return flow does exist, but it varies greatly in time and space, so that it can often be detected only by careful statistical analysis of upper air soundings (see "New Steps in Tropical Meteorology," *NCAR Quarterly*, October 1964).

## *Keys to Tropical Weather*

The trades blow toward the equatorial trough, or belt of low pressure, an area of intense convective activity. This region of the inner tropics has the most even temperatures on earth, and the atmosphere there is in such a delicate equilibrium that almost imperceptible changes in temperature or humidity or the way the air flows can swing the weather from sunny to cloudy to rainy. The accompanying convection, sporadic but intense, makes the trough zone the principal area where heat is transferred from the surface through the cloud layer to the upper troposphere, whence it moves toward temperate regions. (This picture is complicated by the curious fact that most of the convective activity occurs in the northern and southern zones of the equatorial trough, while a central band along the equator has very little rainfall. This pattern is one of the many unexplained features of the tropics.)

We know very little about the dynamics of tropical convection, in spite of notable pioneering studies such as that of Michael Garstang of the Woods Hole Oceanographic Institution, on tropical rainfall patterns, and of Joanne Simpson of ESSA, and her colleagues, on tropical cumulus development. We do know that tropical cumulus clouds are typically organized into widespread systems, which seem to be subtly controlled by the feeble, large-scale tropical wind systems. In turn, the development, growth, and dissipation of such clouds alters the fine balance of heat and humidity sufficiently to react upon the winds, both locally and over wide areas. (This dominance of cloud systems in tropical weather has been made more evident by satellite photographs, and has led Lester Hubert of ESSA to suggest that descriptions of the cloud systems themselves offer the best means of characterizing tropical weather.)

## *A Tropical Program*

The Line Islands Experiment evolved in recognition of our highly incomplete knowledge of fundamental processes of tropical meteorology, a deficiency which was made more pointed early in 1966 when the International Council of Scientific Unions (ICSU) issued its prospectus for a Global Atmospheric Research Program to be carried out during the 1970s. In response to the ICSU statement, and out of concern for their own related research interests, a group of meteorologists representing a number of universities and research organizations held several informal meetings at NCAR during 1966 to survey the needs for better information on tropical weather processes. There were three working groups, chaired by Colin Ramage (University of Hawaii), Noel La Seur (Florida State University) and Jule Charney (MIT), each dealing with one aspect of the plan of attack on the tropics.

It seemed impossible to furnish the tropics with a network of regular weather stations and, as the best alternative, the planning groups evolved the idea of a series of expeditions, in which observations would be made in selected areas for limited periods of time. Obviously, the expeditions, which became known collectively as TROMEX, for Tropical Meteorological Experiment, would have to concentrate on observing programs designed to yield the largest possible amounts of useful data on specific important topics.

The prospect of a synchronous satellite (ATS-1) to be stationed over the

Pacific directed initial attention to the Line Islands. This little string of atolls lay almost directly under the satellite's expected position, and afforded observing sites south of the equatorial trough at Christmas Island (2°N), and extending into the trough at Fanning (4°N), and Palmyra (6°N).

The Line Islands location offered the possibility of investigating an array of important questions in tropical meteorology which have been set forth by Edward Zipser of NCAR, the scientific coordinator of the Line Islands Experiment. Some of these are:

- *The equatorial trough.* Does the trough change position from day to day, or seasonally? Does its behavior near the Line Islands represent its behavior elsewhere?
- *Tropical rainfall cycles.* There seem to be 24- and perhaps also 12-hourly rainfall cycles over even the smallest tropical atolls, and possibly also over the open tropical ocean. Can such cycles be defined in the vicinity of the Line Islands?
- *Cloud system life cycles.* Can patterns of atmospheric instability and of heat transfer from the ocean surface be correlated with tropical cloud-system life cycles?
- *Cumulonimbus convection.* Most tropical cumulus clouds do not rise high enough to carry heat into the levels from which it is likely to be transported poleward. The effective heat supply seems to be provided by the less frequent but more active cumulonimbus clouds which tower to higher levels. Can the character of such convection be made more specific by appropriate measurements?
- *Wind fields from satellite photographs.* If cumulus clouds drifted with the wind, and if we knew their heights, they would serve admirably as both wind vanes and anemometers at the level of the cloud layer. They do not necessarily move directly with the wind, however, because their internal vertical currents create shear stresses which probably cause them to deviate somewhat from the speed and direction of the surrounding horizontal wind. Can we determine these deviations, for various types of cumulus clouds? If so, we can apply the results to interpretation of photographs from synchronous satellites, where frequent successive pictures of the same area make it possible to follow closely the development and motions of cloud systems. Such a method would make satellite photographs far more useful, and would open new research vistas, particularly in tropical meteorology.

These general problem areas provided the context for a number of specific research projects which will take advantage of the data from the Line Islands Experiment. Scientists from at least seven universities, and from NCAR, ESSA, and the Woods Hole Oceanographic Institution are already making use of such data, and additional uses will undoubtedly develop.

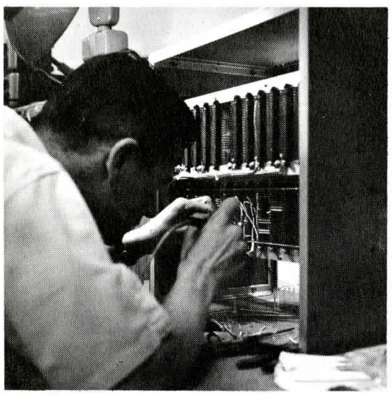
The various routine and special observing programs in the Experiment were provided by the Armed Services, ESSA, and NASA, supplemented by NCAR's facilities. Much of the logistics involved had to be arranged by NCAR, using commercial ships and aircraft, and here the NSF was the main source of financial support. The State Department provided essential help in securing permission to use the islands, and the AEC and Army in setting up housekeeping. The University of Hawaii, with the help of an NSF grant, is analyzing and archiving much of the conventional data secured, while NCAR is organizing the photographic material from the satellites, aircraft, and ground stations.

The Line Islands Experiment is the first in what is hoped will be an extensive series of meteorological expeditions to tropical locations. The areas considered by the planning group for later TROMEX experiments include the Gilbert and Marshall Islands in the Pacific, and the vicinity of Barbados in the Atlantic. The design of experiments to be carried out at such locations will depend in good part on the results which may be forthcoming over the next several months from the Line Islands Experiment.

# THE NCAR LABORATORY

1.

1. **Discussion**
2. **Electronics**
3. **Tape racks, computer room**
4. **Glass shop**
5. **Seminar room**
6. **NCAR Library**
7. **Cafeteria**



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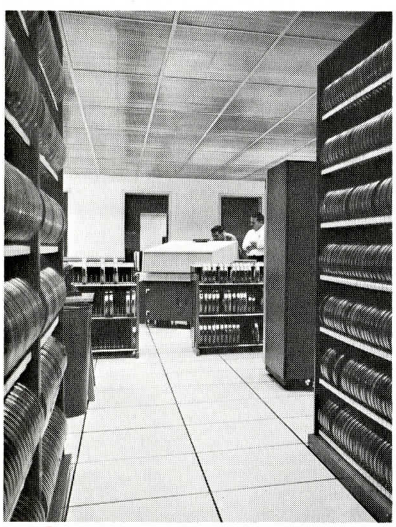

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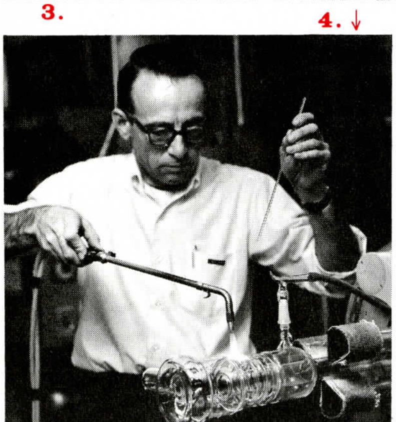

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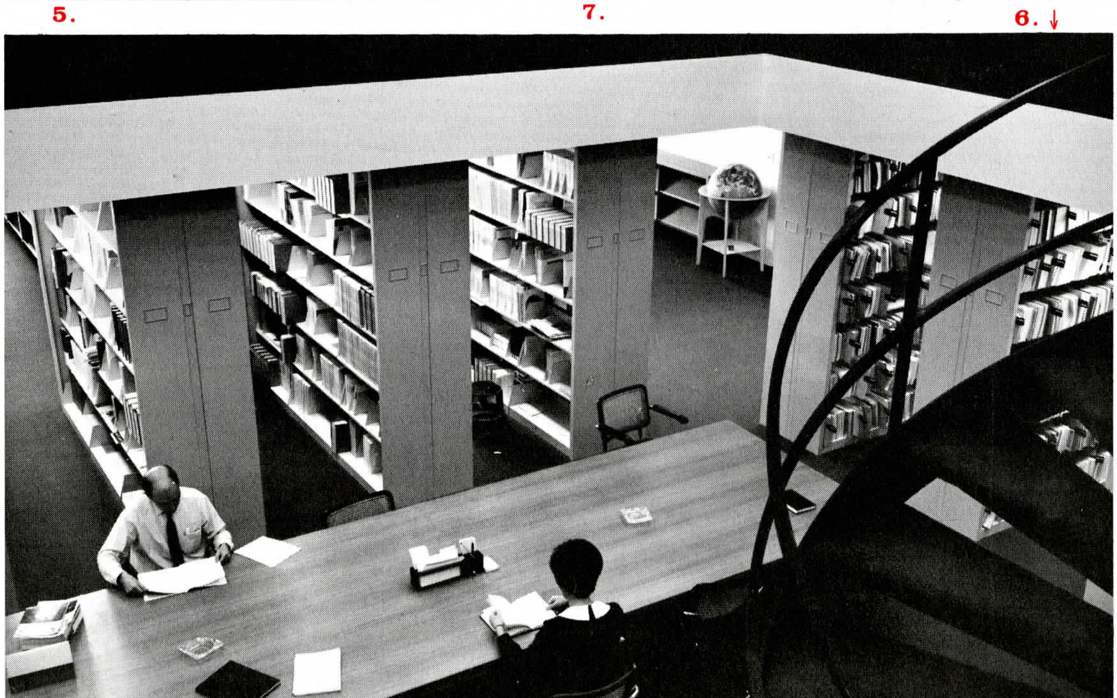


8. The keyhole: east plaza stair

9. Tritium analysis

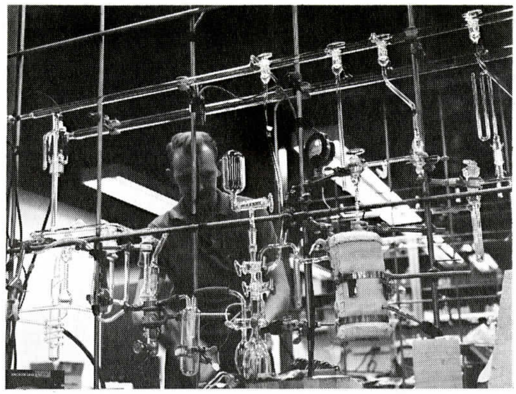
10. Dropsonde laboratory

11. Machine shop

12. Applications analysis

13. Weather maps

14. Lobby



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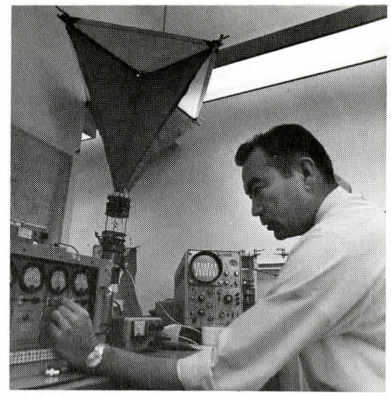

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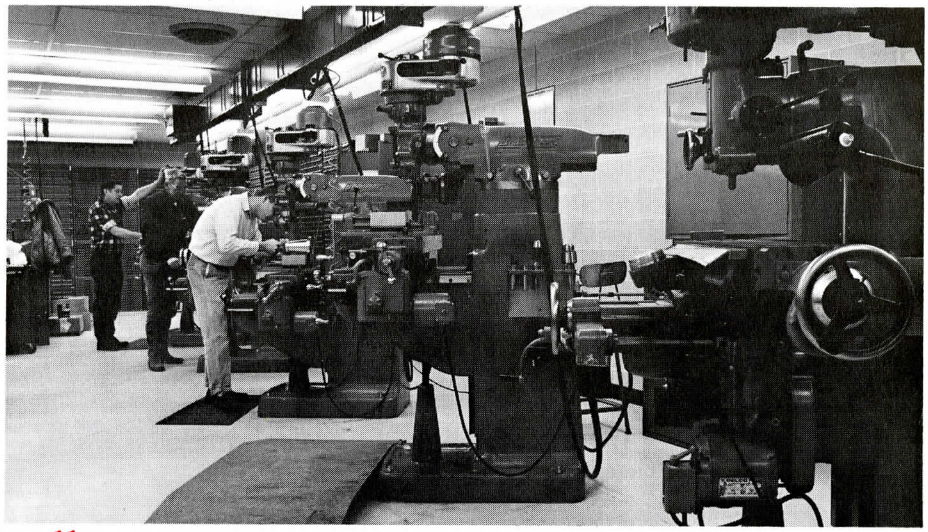

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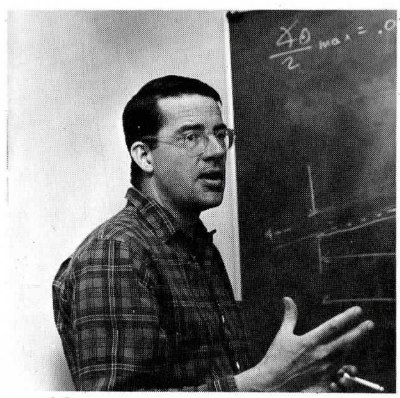

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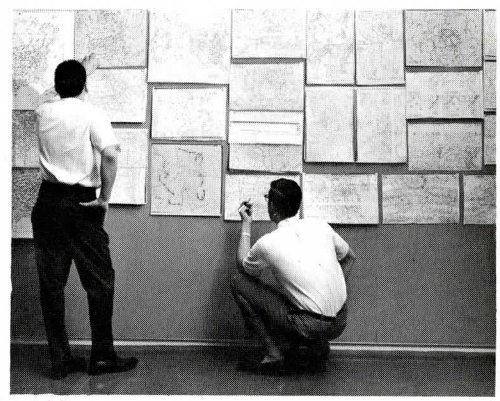

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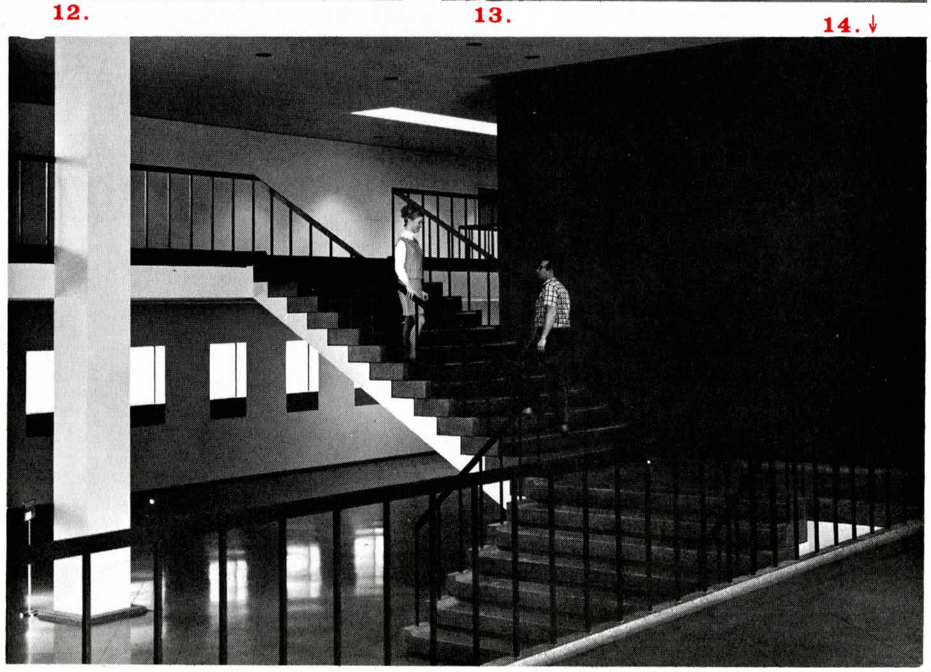
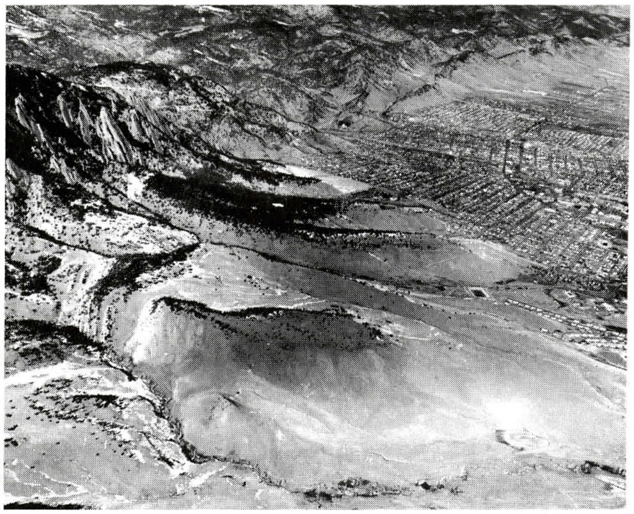
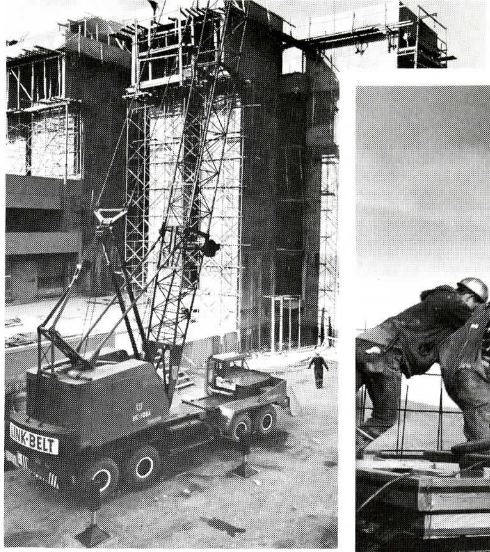
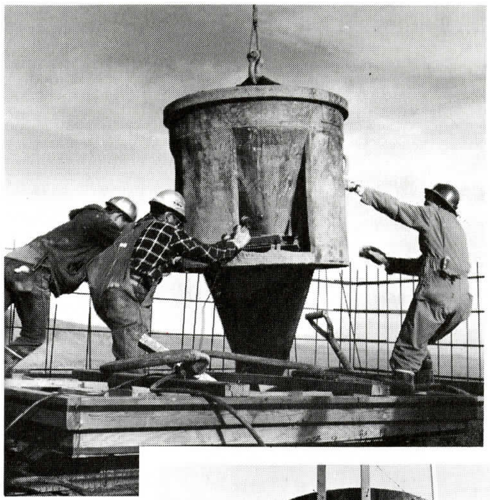
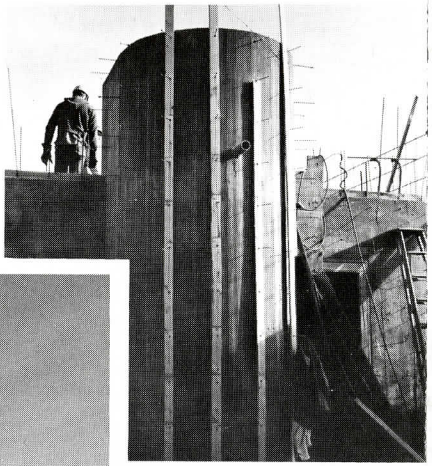


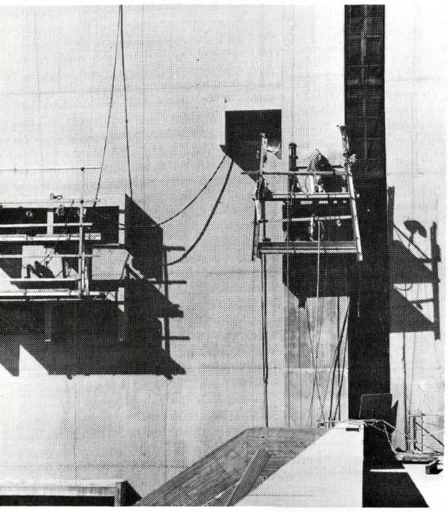


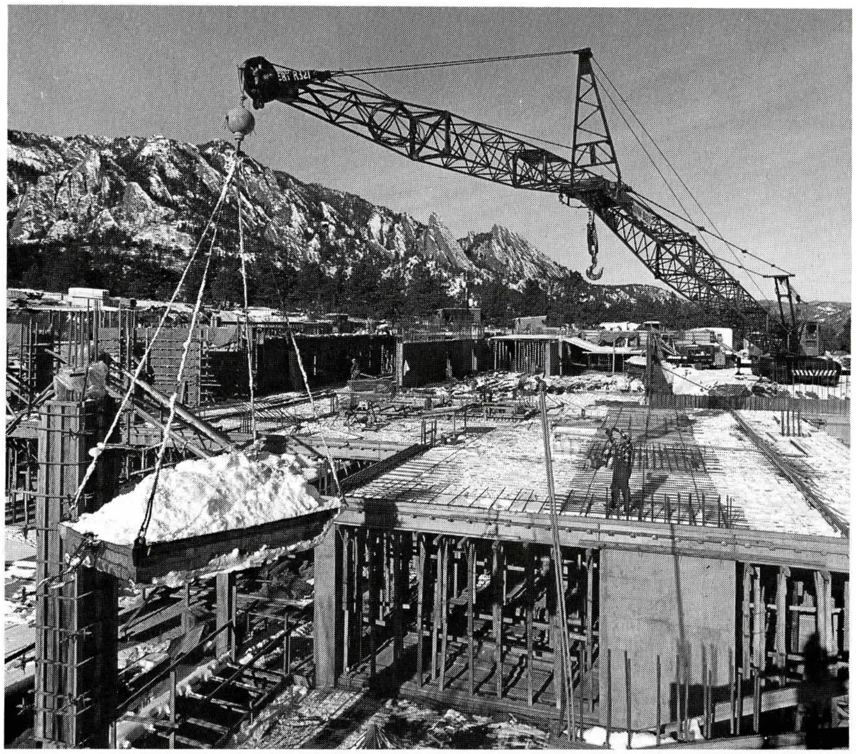


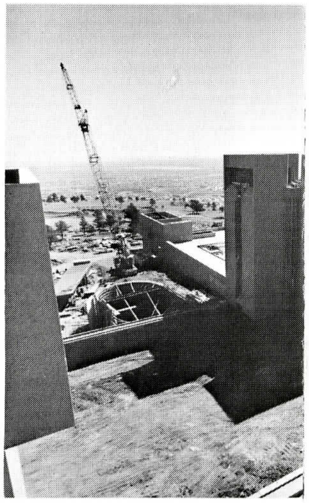


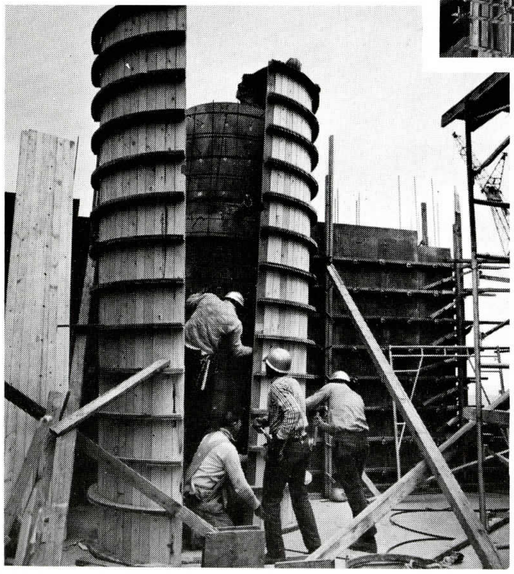
## The site, and construction

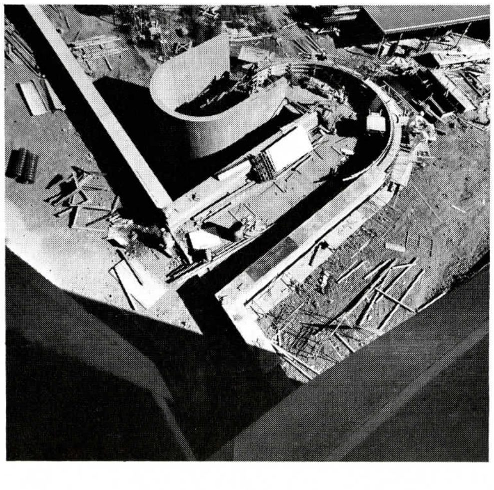


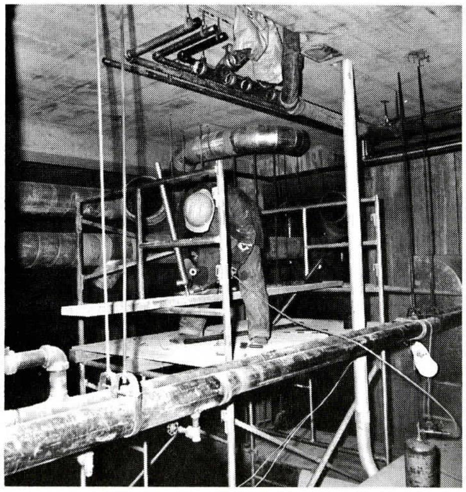












# The 1966 Eclipse

For many years NCAR's High Altitude Observatory has specialized in studies of the solar corona, the outer part of the solar atmosphere. Since total eclipses of the sun provide the only presently available opportunities for observing the fine structure of the corona, a number of research institutions sent expeditions to South America to observe the eclipse of November 12, 1966. Three High Altitude Observatory expeditions—to Bolivia, Peru, and Brazil—carried out an array of experiments relating to the corona and to the earth's upper atmosphere. The preliminary results from most of these experiments appear quite promising, although their ultimate scientific importance will be determined only by patient data reduction over the next several months or even years.

## *Bolivia*

The Observatory sent a nine-man team, headed by Gordon Newkirk, to the high arid plateau of Bolivia—the "altiplano." The path of totality crossed other regions which were more accessible, but the altiplano (elevation, about 13,000 feet) offered cleaner air and hence less light-scattering for coronal observations, plus a climate which gave a good chance for a cloudless sky on the morning of the eclipse.

In June, Keith Watson made a preliminary visit to Pulacayo, on the altiplano, to scout the routes for air and ground shipments of supplies and scientific equipment, and to investigate possibilities for living quarters. The members of the expedition traveled to Pulacayo in three groups, in October and November, each with a layover of a few days in La Paz to get used to the altitude.

In Pulacayo they found that maps of the region were not accurate enough to determine the true path of totality on the ground; consequently Newkirk's colleague, J. M. Malville, and William Hatt, a graduate student at the University of Colorado, carried out a survey using basic astronomical techniques. The path of totality was about 50 miles wide, and the experiments had to be located within five miles of the center of the path. The site Hatt and Malville selected turned out to be three miles from the center of the path.

The Observatory party had two sets of experiments in Bolivia, one supervised by Malville, the other by Newkirk. Malville's experiments investigated the possibility of detecting coronal magnetic fields by measurements of a line in the coronal spectrum which represents emission from Fe XIII, the stripped-down atom of iron from which twelve planetary electrons have been removed by the extremely high temperature of the corona. Observations of the Fe XIII line at previous eclipses had confirmed the theoretically predicted polarization, and Malville hoped to get new data by making photoelectric measurements of the intensity and polarization of this line. The instrument he used was a 10-inch Cassegrain telescope which feeds light via a mirror to a photoelectric analyzer.

Newkirk's experiment was aimed at securing a white-light photograph of the corona. He used a simple, rugged, white-light telescope designed and built by himself and Leon Lacey. His greatest problem was to accommodate the wide range in intensity of light from the corona. At a distance of six solar radii, the light from the corona is about one ten-thousandth as intense as it is at the edge of the sun. Although the human eye can register this wide range, photographic film cannot. (Snapshots of the corona at eclipses are almost always successful, because almost any camera setting will get a picture of *part* of the corona.)

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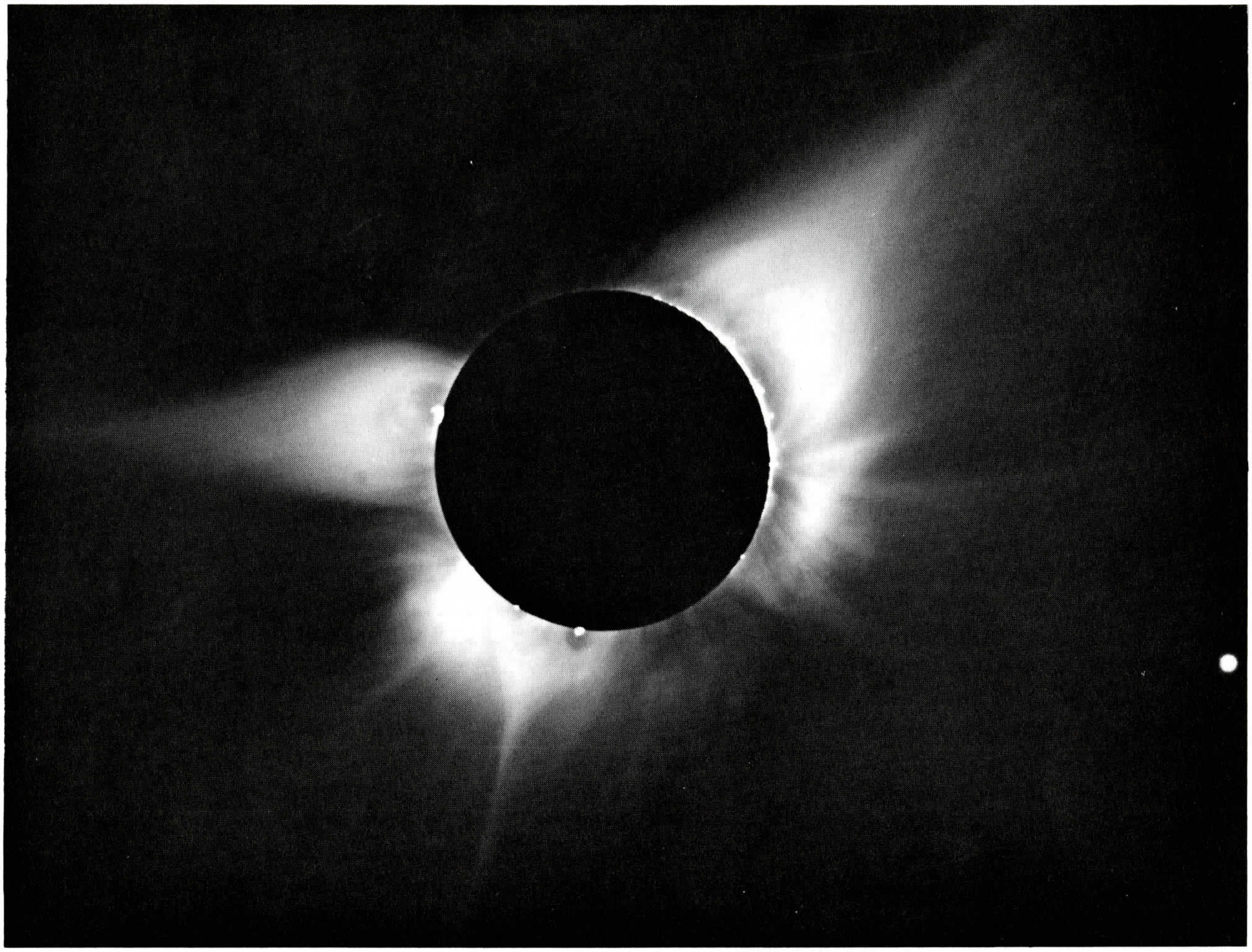
The National Center for Atmospheric Research was established in 1960 to conduct and foster basic research in the atmospheric sciences, to supplement and augment the research and educational programs of universities and research groups in the United States and abroad, and to work toward increasing the effectiveness of atmospheric research efforts as a whole. It is operated by the University Corporation for Atmospheric Research, a private non-profit organization, and sponsored by the National Science Foundation.

In pursuit of its goals NCAR seeks to develop interdisciplinary research programs across the broad spectrum of the atmospheric sciences; to develop major research facilities essential to national and international interests in the atmospheric sciences, and to carry on strong and continuous communications and cooperation with universities and the scientific community.

NCAR is comprised of four scientific divisions: the Laboratory of Atmospheric Sciences, the High Altitude Observatory, the Facilities Laboratory, and the Advanced Study Program. NCAR receives primary support from the National Science Foundation. Contracts, grants and gifts are also provided by other government agencies, and by individuals, corporations, and foundations.



*Gordon Newkirk's white-light photograph of the corona, Bolivia, 1966.*

A possible solution has been known for some time: use a graded filter which balances the variation in intensity, by heavily masking the light close to the sun's limb, and letting in progressively more light from more distant parts of the corona. However, the difficulties are formidable: first, of producing a filter with such a wide range of absorption but with no asymmetries or imperfections; then, of centering it exactly on the eclipsed sun; and, finally, of estimating the exposure which will give the best possible picture, since the wide range of brightness of the corona is compressed by the filter almost to a single value.

Newkirk found a small California firm which made a superb filter, with a range of 10,000 in transmission, and with far greater accuracy than he had hoped for.

To allow for all possible solar motions, some of which could only be determined on the morning of the eclipse, he had to make centering adjustments until just before the start of totality. Then, at just the right instant, he had to start the automatic programmer which carried out a pre-determined sequence of exposures, with and without filters and polaroids, in the somewhat less than two minutes of totality afforded at the Bolivian location.

Newkirk's greatest achievement, in the eyes of his colleagues, was that he *did* choose the correct exposure: when the negatives were developed they revealed one of the finest white-light pictures of the corona ever obtained.

Leon Lacey handled problems of mechanical equipment in the Bolivian experiments, and Howard Hull the electronics problems. Several expedition members took part in Malville's experiments: David Hultquist, on loan from the University of Hawaii, and Edward Schmahl, a graduate student at the University of Colorado, as well as William Hatt. Keith Watson returned to Bolivia with the expedition in November, to supervise logistics. The ninth member of the expedition was Fernando Sheriff, a graduate student at the Laboratorio de Fisico Cosmica at La Paz, who came to the United States before the eclipse, and later assisted in Bolivia with such essential matters as making reservations, receiving shipments, and interpreting, and with the experiments as well.

## *Peru*

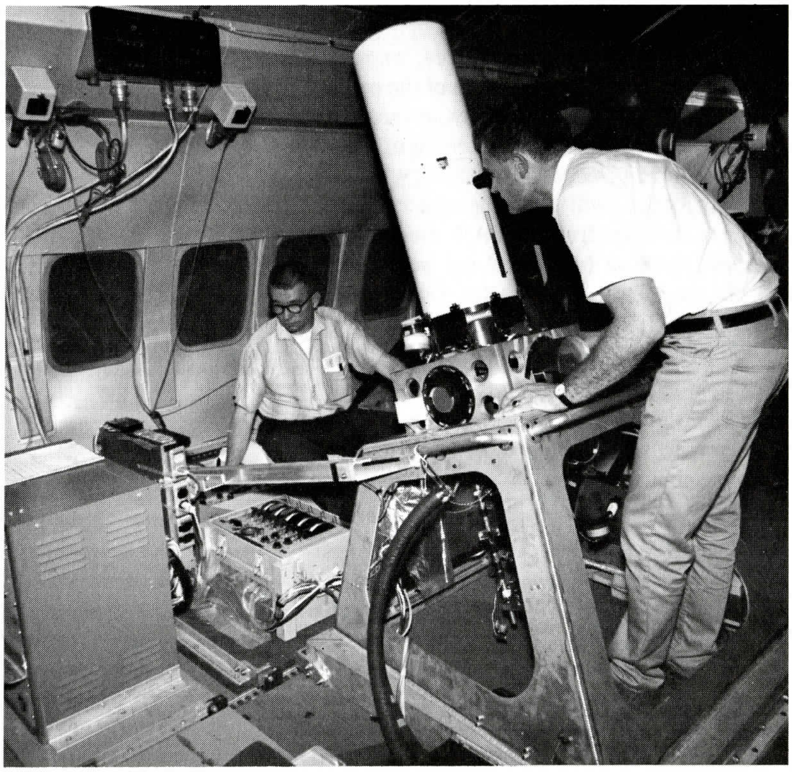
The expedition to Peru, devised by Sadami Matsushita and carried out by Dallas Tanton, was not a coronal study but a long-shot attempt to measure changes in the earth's magnetic field due to cooling of the ionosphere during the eclipse. This experiment, conducted near Lima in cooperation with the Instituto Geofisica Peruiana, produced a record which seems rather improbable, and the Observatory people feel that "either something went wrong, or we discovered a lot of new things." The data will be shelved until some future low-latitude eclipse provides another record for comparison.

## *Brazil*

Cloudy skies are the greatest hazard for eclipse expeditions. One way to avoid them is to fly the observing instruments above the weather. Aircraft altitudes also provide relative freedom from dust and water vapor, both of which degrade observations of the corona. An aircraft flying along the eclipse path can prolong the time of totality by a few minutes—enough to provide significant gains in the amount of data that can be secured. (The eclipse shadow travels at 1000 mph, the airplane we are about to discuss at 500 mph.) The primary drawbacks of airplanes are engine vibration, which must be damped out as far as possible at the instruments, and various motions of the aircraft such as the ever-present rolling motion.

For the 1966 eclipse, the NASA Airborne Science Group furnished its Convair 990 jet aircraft, which accommodated ten experiments conducted by teams from several research institutions. The High Altitude Observatory experiment sought to record the polarization of light in the Fe XIII line on film, rather than photoelectrically as in the experiment on the ground in Bolivia.

This experiment presented some severe optical problems. Polarization of the corona increases outward from the sun, and is most evident in the fainter corona, which, however, is far harder to observe than the inner corona. Also, the Fe XIII line is in the infrared portion of the spectrum—which is the most difficult portion to register on film. Part of the solution was to use an image converter to transform infrared radiation into visible light. In addition, the telescope platform had to be stabilized in relation to the aircraft motion, including compensations for course corrections and turbulence. Robert Lee, head of the Observatory's electronics shop, was aboard to monitor the stabilizing equipment which sensed the aircraft motion and held the telescope steady against it. The scientists in charge were John Eddy, and John Firor, Director of the Observatory. During the eclipse flight Eddy assisted Lee in checking the orientation of the telescope while Firor assisted



*NCAR's solar telescope aboard NASA's Convair 990 research aircraft. Robert Lee monitors the stabilizing equipment as John Eddy orients the telescope. Windows were sealed during the eclipse flight to eliminate outside light. Photo courtesy of NASA.*

Richard Dunn of the Sacramento Peak Observatory, New Mexico, in a different experiment.

This airborne program involved about 80 hours of flight time, and nearly 50,000 miles of travel, including check flights before and after the eclipse. For the event itself, aircraft and experiments were moved to Porto Alegre, in southern Brazil, where repeated check flights were run over the Atlantic along the eclipse path. NASA not only provided the aircraft but also made many of the necessary arrangements in Brazil, assisted by the Brazilian Space Committee.

On the actual eclipse flight the aircraft flew a curved path for 23 minutes, keeping the sun almost exactly abeam of the aircraft by autopilot (the curving was to compensate for the sun's westward motion). The autopilot reduced aircraft motions to about one-half degree of arc. The gyro system on the Observatory equipment further reduced the remaining motion so that the instrument kept its orientation to within 5 seconds of arc—about four times better than had been hoped for in designing the gyro platform.

This eclipse experiment was the Observatory's first experience with a gyro platform for airborne observations, and the results strongly indicate the potential value of further airborne astronomical experiments.

# Notes

## UCAR Reorganization

On May 9, UCAR will take the final step in a corporate reorganization under which its 23 member universities will attain equal voices in choosing corporate management. This step completes a transition that began in 1963, when the 14 charter universities of UCAR decided to reopen the membership.

The current Board of Trustees, composed of two representatives from each of the original 14 universities, and six trustees at large, will hold its last meeting on the morning of May 9. The reorganized Board of Trustees, which will then take office, will be composed of sixteen members, twelve from UCAR member universities, three at large, and the president of UCAR ex-officio, Dr. Walter Orr Roberts, who is also Director of NCAR.

Henceforth, one-third of the Board of Trustees will be elected each year, to three-year terms, at an annual meeting of members, to which each university will send two representatives.

Membership in UCAR is open to universities with continuing commitments to programs leading to the doctorate in the atmospheric sciences or closely related fields. NCAR programs, facilities, and services are available to scientists from universities (whether members of UCAR or not) and other research groups in the United States and abroad.

## New Buildings for NCAR

The Max C. Fleischmann Foundation of Nevada has granted NCAR $100,000 for construction and furnishing of an Advanced Study Program "complex"—a group of three small one-story buildings containing offices and seminar rooms for visiting scientists, to be erected near the NCAR Laboratory. The principal purpose of these buildings is to furnish quiet space for non-laboratory study.

The exact site and design of the ASP buildings are not yet decided upon; it is expected that a local architect will design them, and that they will be in harmony with the NCAR Laboratory and its natural setting. The complex will probably consist of two office buildings, connected by covered walkways to a central seminar building, which will also contain the director's office, an office for his assistant, and a small kitchen. A protected outdoor "spot-beneath-the-trees" will invite discussion and meditation in good weather.

Offices will be large enough so that each can serve three program participants during the busy summer months, and in winter will provide more than adequate room for ASP's long-term visitors. The seminar room will be equipped for alternate use as a classroom or lounge, and it is hoped that here, as in previous years in Cockerell Hall, many stimulating discussions will attract and involve ASP participants.