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Atmospheric Research: A Powerful Concept Emerges

U.S. universities, aided by a new research center, now stress rigor, breadth, joint efforts.

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Some 20 years ago, if you asked a bright undergraduate physics student if he would like to be a meteorologist, he might well have replied, "No thanks, I'd rather be a scientist."

Since then, there has been a revolution in the study of the atmosphere. The emphasis has shifted from descriptive and qualitative aspects to applications of fundamental physical laws and their rigorous mathematical formulations. Meteorology's ancient ties to physics, chemistry, astrophysics, oceanography, and mathematics have been renewed. We now use the term *atmospheric sciences*, by which we mean a tightly knit family of disciplines and branches of physical science concentrated on a broad but single objective: to understand man's natural atmospheric environment in terms of the many interactions between competing processes, no one of which is consistently dominant.

New tools and hardware have played a part in the revolution—high-altitude airplanes and balloons; rockets and satellites; new instruments for making observations; new signal sources and sensors; lasers and thermistors. Perhaps the most important new tool is the electronic computer, without which the many complex physical processes simultaneously at work in the atmosphere could never be treated in a unified, comprehensive way.

Useful as these tools are, however, it is new *concept* that has transformed the atmospheric sciences. Probably the single event of most importance to atmospheric research since World War II is the development of the logical design of computers at the Institute for Advanced Study, in Princeton, in the late 1940's, and the application of this development to meteorology. The Princeton group, headed by John von Neumann, recognized the power of new mathematical concepts to aid in analyzing the atmosphere. We may soon be able to roughhew and then refine mathematical models of the atmosphere, make long-range predictions based on these models, and perhaps then test the feasibility and effectiveness of proposed methods of weather modification and control.

First, of course, individual processes which alter the energy balance in the atmosphere must be more fully understood. Despite the scarcity of skilled researchers in the atmospheric sciences in the first 10 years after the war, much significant work in this field has been done. We have gained new understanding of precipitation and cloud electrification processes, of the role of ozone and aerosols in the upper atmosphere, and of sea-air interactions, and we have made advances in atmospheric optics, in ionospheric and plasma physics, and in other fields.

Shortcomings

Despite such advances, the pace of progress in the atmospheric sciences has been too slow. There are still not enough skilled and creative workers in atmospheric research. Educational efforts to produce the next generation of sophisticated researchers are lagging behind the need. Certain basic problems, such as the development of a general theory of turbulence and a model of the dynamic coupling of oceans and atmosphere, are only beginning to be attacked in an adequate way. Finally, far too little has been done to integrate the results of individual research and to initiate cooperative efforts on large, interdisciplinary problems whose solution is essential to a full understanding of the atmosphere.

In recent years, as the existence of an "atmospheric sciences gap" has become obvious, the public has begun to demand applicable results. In a world beset by drought, severe storms, and a population explosion which requires management of natural resources, people become impatient. There has been, for example, great hope that cloud-seeding will prove generally effective as a rain-producer, even though it has been successful only in certain well-defined cases. Terms like "weather control" have been bandied about as if it were only a matter of time until the large-scale circulation of the atmosphere could be harnessed or influenced, but the possibility of even a moderate degree of control is far off, and we cannot yet calculate the odds of success.

Nevertheless, this interest on the part of the public is both welcome and to some extent justified. Some practical applications of atmospheric research are certainly closer to realization than the control of rain by seeding. Among such goals are the control of air pollution; a better knowledge of the near-space environment; and, of course, the development of more accurate methods of long-range weather prediction.

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These goals clearly justify the investment of substantial amounts of public funds in atmospheric research. But it will be some time before we reach them, and public support must be sufficiently steadfast to allow full exploration of the basic research aspects of these problems.

How To Get Organized?

The question in the mid-1950's was: How can we best mount an attack on fundamental atmospheric problems commensurate with their scientific and practical potential? In 1956 the National Academy of Sciences asked this question of its Committee on Meteorology (later renamed the Committee on Atmospheric Sciences), under the chairmanship of Lloyd V. Berkner.

The committee, in its report (*1*), recognized both the challenge facing the atmospheric sciences community and the inadequacies of the existing means for meeting it. Far too few well-trained research scientists were being turned out in the graduate schools. Except at a very few institutions, graduate study was narrowly limited to conventional meteorology. Essential connections with other relevant disciplines were insufficiently developed. Even where atmospheric scientists had imaginative plans, a lack of research facilities was hampering their progress.

The committee made three major recommendations—first, that the scale of effort in atmospheric research in the universities at once be increased 150 percent, and that financial support be made more stable and continuous; second, that the American Meteorological Society increase its activities "in stimulating interest in meteorology tenfold or more"; third, that a national institute for atmospheric research be established as promptly as possible.

In response, 13 universities with active interest in the atmospheric sciences formed a committee to make plans for establishing such a center. Under the chairmanship of Henry G. Houghton of the Massachusetts Institute of Technology, the committee held 17 two-day meetings, attended by more than 150 scientists, to discuss how various research problems should be attacked in such an institute. The committee also held countless informal conferences to decide how the center and its governing body (soon to be called the University Corporation for Atmospheric Research, or UCAR) should be organized. The resulting product was a detailed plan (*2*), submitted to the National Science Foundation in February 1959, for a National Institute for Atmospheric Research, now known as the National Center for Atmospheric Research (NCAR).

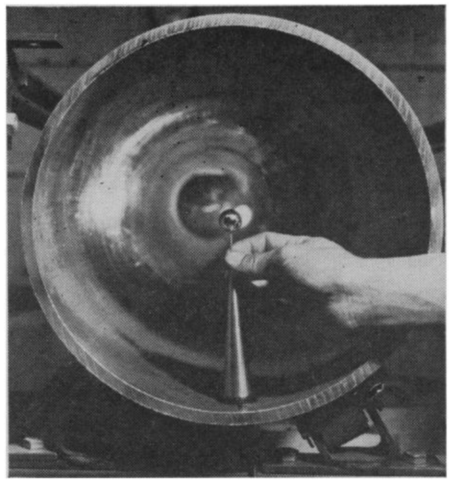

Fig. 1. Study of particle trajectories as a basis for calculating the particle-capture efficiencies of raindrops. Here a perfect sphere is placed in an airstream (1.6 to 16 km/hr) containing zinc sulfide particles. The area concentration and the size distribution of the particles deposited on the sphere are recorded, and from these data trajectory and velocity are calculated. [Gallet, Boulder, Colo.]

In the introductory chapter of the report the context in which the new center was to operate was made clear.

"This report is expressly addressed to the question of the Institute. It should be clearly recognized, however, that the Institute is only one part of the general program for expansion of research on problems of the atmosphere. Sight must not be lost of the fact that everything that follows is predicated on the assumption that meteorological research effort at the universities will be strengthened. It was not by accident that the Academy Committee on Meteorology gave first priority to the university research program. The wisdom of this ranking was strongly affirmed by UCAR, by the representatives of the university administration, and by the scientists in the series of conferences."

Thus, the major concern of the atmospheric science community was, clearly, progress in the universities. Major goals of NCAR became, and continue to be, the promotion and fostering of research and education in the university community.

A month after the plan was published, 14 universities became incorporated as the University Corporation for Atmospheric Research, and in June 1960 an initial allocation of $500,000 was made by NSF. The center was under way, and I took up my duties as its director.

The board of trustees, led by Horace R. Byers of the University of Chicago, chairman, and A. Richard Kassander of the University of Arizona, vice chairman, is composed of two representatives from each of the 14 original member universities and six trustees-at-large (*3*). When membership in the corporation was recently opened to all universities that have programs leading to the granting of doctorates in the atmospheric sciences, five more universities (*4*) joined the corporation. The board of trustees deals primarily with corporate and management matters, while the task of reviewing NCAR's performance and goals has now been assumed by a new body, the UCAR Council of Members, on which all member universities—old and new—are represented. The council will, I believe, play an increasingly important role in assuring that NCAR responds accurately and effectively to the changing needs of the university atmospheric sciences community.

Roles for NCAR

The 1959 UCAR report made it clear that the new center would be, first and foremost, a basic research laboratory, with a resident staff and a vigorous program of long- and short-term visits from nonresident scientists. The research program must be first-rate, or else none of NCAR's activities would be. It should be based on the broadest possible concept of the atmospheric sciences and should include studies of influences extending to the innermost and outermost frontiers of the atmosphere.

The 1959 report also stressed the goals of education, especially at graduate and postdoctoral levels. It was my conviction that these goals should be pursued with vigor—not by making NCAR a degree-granting institution but by making available the NCAR facilities and the services of the NCAR staff to all universities which had programs in the atmospheric sciences, or planned to initiate such programs.

The other roles for the new center were set forth in the report: (i) it should be a place where cooperative research projects and joint use of facilities can be planned; and (ii) when no other agency or university is in a position to provide a facility clearly needed by the university community, NCAR should consult with representative groups and endeavor to provide it.

The touchstone of NCAR's research effort might well be a sentence in the first UCAR study of the need for a national center: "In the light of man's mastery of matter and energy, this ignorance of his large-scale physical environment is striking and incongruous." The ignorance is so broad that we must feel our way. We can identify many promising areas, but we do not securely know the most promising direction toward fuller understanding of the atmosphere's overall behavior.

Therefore, the nation's effort in atmospheric research must be balanced between small undertakings that are "sure things" and larger gambles for major payoffs; between investigations for which one can predict applicable results within a given time and others for which one cannot; between projects pursued by well-organized groups with clear goals and others pursued by individual scientists making stabs into the darkness.

Research Program

The NCAR research program reflects an awareness of divergent demands and the necessary breadth of attack. The High Altitude Observatory (HAO), concentrates on solar, interplanetary, ionospheric, and upper atmospheric processes; the Laboratory of Atmospheric Sciences studies the regions from about 100 kilometers down to the earth's surface, and the coupling of the atmosphere and the ocean or land surface.

Obviously no laboratory can deal with every aspect of such a large interdisciplinary field. We do not try to. Instead, we concentrate on several areas.

In the Laboratory of Atmospheric Sciences, headed by William W. Kellogg, these areas are as follows.

1) Atmospheric chemistry, in which a number of NCAR scientists are investigating various phases of the life cycle—the sources and sinks—of trace gases and aerosols in the atmosphere. These trace gases and aerosols partially govern the radiation balance, contribute to air pollution, play critical roles in the processes of condensation and precipitation, and are useful as tracers of large-scale circulations, especially in the stratosphere.

2) Cloud physics. This is a broad province in which NCAR scientists are investigating the role of aerosols as freezing nuclei; the detailed growth of ice crystals; vertical motions within clouds; collection efficiencies of large falling droplets (Fig. 1); and the roles of atmospheric electricity and shock waves in the processes of condensation, coalescence, and precipitation.

3) Atmospheric dynamics. In this area experimental and theoretical studies of circulation are being carried out. These deal with circulation on many scales, from small-scale turbulence to hemispheric circulations. We are, for example, extensively investigating the basic nature of turbulent transport of energy, using our large computer to simulate three-dimensional observations and comparing the results of laboratory experiments with results from the computer. In a large-scale study NCAR has engaged in the design of a numerical model of the atmosphere, building on the experience of such dynamicists as Leith at the University of California's Lawrence Radiation Laboratories; Mintz at the University of California, Los Angeles; Phillips at the Massachusetts Institute of Technology; and Smagorinsky at the U.S. Weather Bureau. The model will ultimately incorporate processes not yet realistically simulated, such as the effects of clouds and rain on the heat budget. We hope that, from this study, a reliable model of the behavior of the

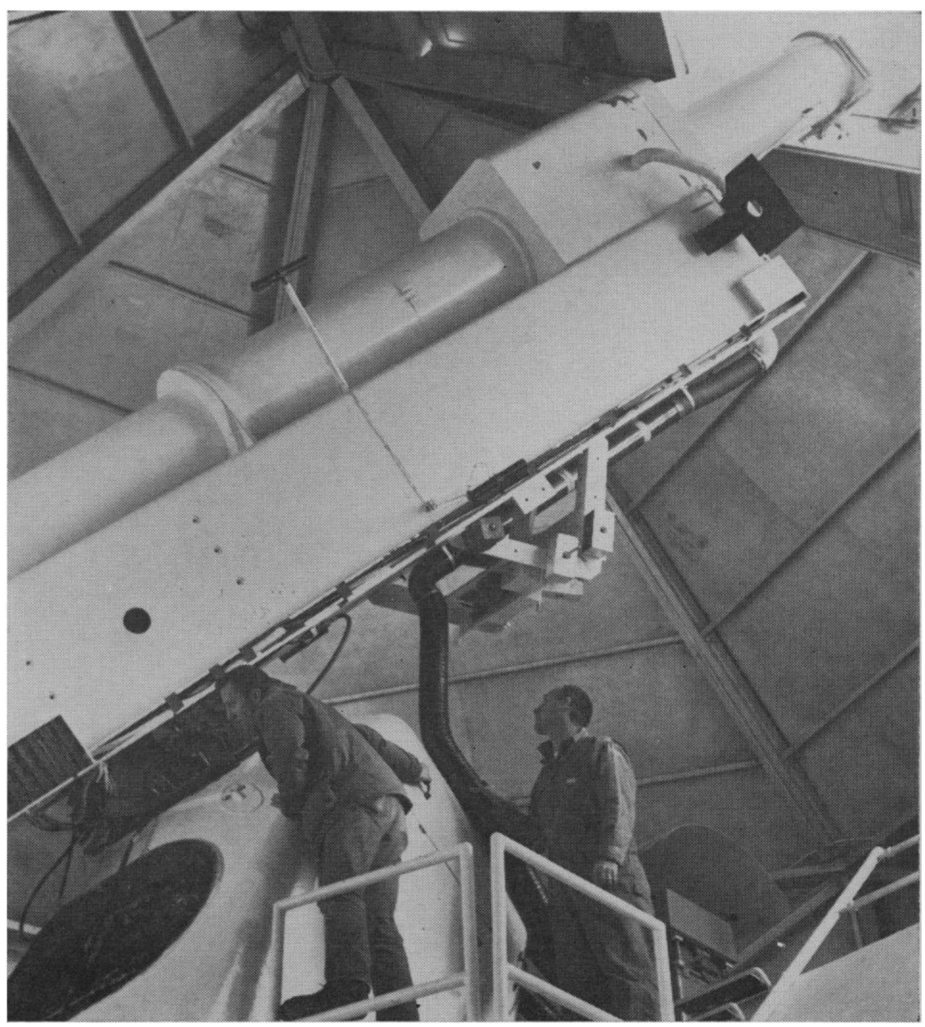

Fig. 2. Coronagraph (40 cm) mounted on a 7.8-meter equatorial spar in one of the two domes at the Climax Observing Station (elevation, 3350 m).

atmosphere will eventually be developed, which can be used for long-range weather prediction and for testing various schemes of large-scale weather modification or control.

At the High Altitude Observatory, under the direction of John W. Firor, the major areas of interest are:

1) The structure of the solar atmosphere. Most of the processes of the solar atmosphere are as yet only partially understood. Though most HAO scientists are based in Boulder, the main observing tools are at the Climax (Colorado) Observing Station, where HAO was started more than 20 years ago as an independent research laboratory affiliated with the University of Colorado; it merged with UCAR in 1961. The techniques used are mainly spectroscopic. Conventional telescopes and coronagraphs [including a new 16-inch (40-cm) instrument] are used to produce artificial eclipses on all clear days. We also need data gathered in the zone of totality during natural solar eclipses, and the Observatory sends expeditions to obtain these data.

When we study the processes of the solar atmosphere we are dealing with more than the sun's behavior as a simple gaseous sphere. We must consider various complicated and changeable features—sunspots, plages, filaments, prominences, flares, surges, and radio bursts. These are studied by many means, including filter photographs, spectrograms, radio spectra, and ionospheric effects. At present HAO is principally concerned with the roles of magnetic fields and fast particles, which produce effects that are felt throughout the solar system, influencing radio communication and affecting instruments and personnel in space vehicles.

2) The outer solar corona, a region of multimillion-degree temperatures. Investigation of the outer corona provides insights into the overall behavior of the solar machine and yields information about propagation of gases and particles outward into space. This research is based at present on data from eclipse studies, on observations from land-based and balloon-borne coronagraphs, and on photoelectric techniques. The HAO scientists are now supervising the design and construction of a coronagraph to be carried aboard a satellite; this will provide near-continuous observations of variable solar activity in the corona.

3) Interplanetary space and the ionosphere. HAO's continuing interest in this field is shared by many other research groups. Noteworthy at present are its studies of the relationships between geomagnetic and ionospheric events, of radio-star scintillation, and of radio emissions from the planet Jupiter. This work is closely tied to that of our neighbor institute, the Central Radio Propagation Laboratory of the National Bureau of Standards, in Boulder.

The High Altitude Observatory's Climax Observing Station, the site of two domes for solar observation (see Fig. 2), has served solar physicists since 1940. Several long-standing observational programs are being carried on. These include spectral observations of coronal calcium, nickel, and iron and observations of prominence spectra and of spicules (the spicules were first recognized and measured at the Climax station). Solar data are gathered daily from Climax, from the Sacramento Peak (N.M.) Observatory, from the HAO radio astronomy site north of Boulder, and from other points around the world, through a network operated by the Central Radio Propagation Laboratory. Summaries of solar events are distributed weekly and monthly to scientists in this country and abroad by HAO and other co-operating groups.

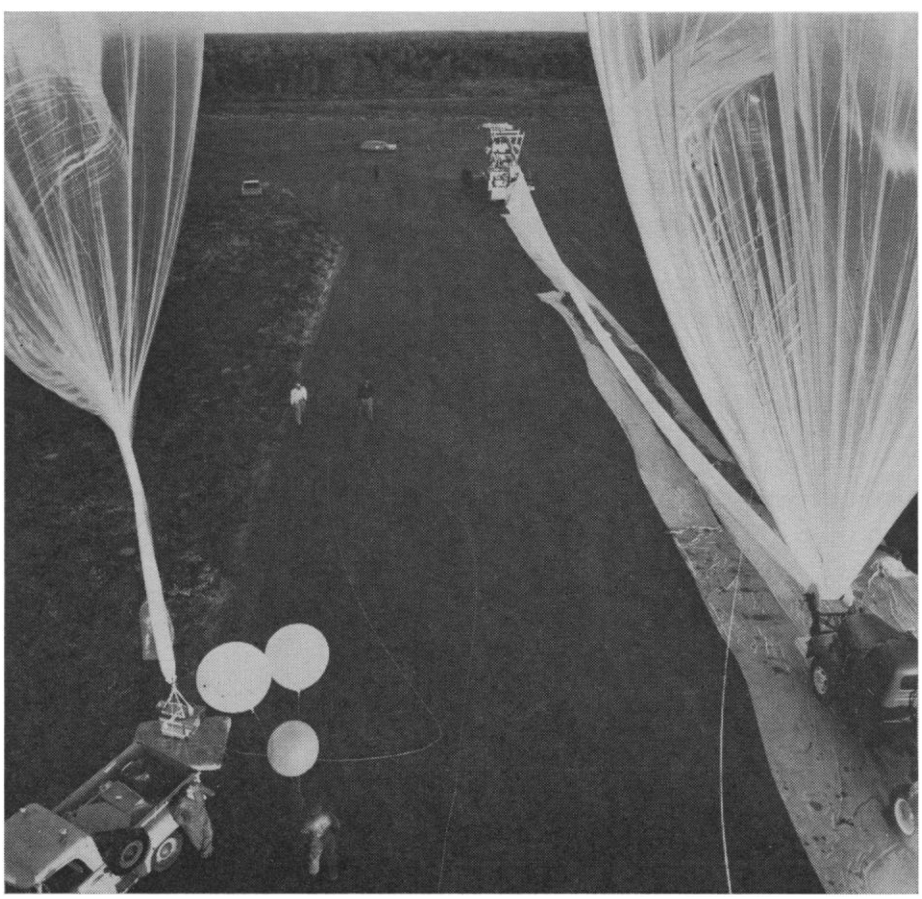

Fig. 3. Two balloons at the NCAR Scientific Balloon Facility shortly before launch on 13 November 1964, with specially designed three-wheel launch vehicle in background. For reasons not understood, balloons larger than about 84,000 cubic meters have had a higher rate of failure than smaller balloons; the failures frequently occur during ascent. Here a tandem system is being launched to study the in-flight dynamics. After launch, cameras were pointed downward from the upper balloon (left) toward the top of the large balloon (82,300 m^3) at lower end of a 90-meter tether. Photographic exposures were made every 5 seconds. At 14,000 meters the test balloon ripped, and the cameras successfully photographed the failure.

Interdisciplinary Problems

The research staff of the two laboratories now numbers 160, including about 53 Ph.D.'s (some 20 visiting scientists are not included in these figures). The staff members are organized, not into departments, but according to the programs in which they are engaged. Joint research projects can then be formed as loose and temporary coalitions of people interested in different aspects of the same general problem. This method of organization provides the flexibility necessary for interdisciplinary research.

To bring into being a vigorous, truly interdisciplinary effort among creative, and consequently firm-minded, scientists, is difficult. Obviously, the efforts of these scientists cannot be legislated. They often arrive at NCAR with unfinished projects and plans for future steps. Joint research efforts among creative scientists can emerge only when they are brought together for long periods under noncoercive leadership and given opportunities for close communication and the development of mutual confidence. Such joint efforts have never before been adequately encouraged in the atmospheric sciences. We feel that our attack is a pioneering effort, and we believe it is beginning to bear fruit.

Looking far into the future is the special task of the Advanced Study Program, under the direction of Philip D. Thompson. Among its activities will be the creation of special seminars in which small groups of invited scientists will join with members of the NCAR staff to assess the status of work in critical areas—for example, the development of a fundamental theory of turbulence.

Of all the NCAR activities, the Advanced Study Program is the most closely related to education. It provides postdoctoral appointments for atmospheric scientists, to give them a broad look at the field and allow them to plan and begin their research careers. It brings university scientists in physics, chemistry, and other basic disciplines to NCAR, where they may probe the relationships between their fields and the field of atmospheric research. It coordinates plans for visiting scientists. These include plans for the summer visitor program, instituted in 1961, which brings 25 or more scientists to Boulder each summer.

Ties with Universities

The Advanced Study Program also does much to initiate and maintain close working relationships with universities which have either well-established or new programs in the atmospheric sciences. Members of the NCAR scientific staff may participate in various ways in efforts to aid university programs: by giving advice and assistance in setting up new departments; by allowing graduate students (with the permission of the university) to come to NCAR to attend seminars or to do their thesis work with NCAR staff members; and (on the initiative and approval of the university) by allowing NCAR staff members to have continuing roles in university programs and to be listed as visiting professors in the university catalog.

The Facilities Division of NCAR, under the direction of Daniel F. Rex, has a similar opportunity and responsibility for forging useful ties with the universities. In the atmospheric sciences, as in other fields, there are many needed facilities that the average university has neither the money to build nor the manpower to maintain. Thus, from the outset, the role of NCAR in making such facilities available for joint use was obvious.

Today NCAR operates a mature joint-use facility in scientific ballooning (see Fig. 3) and two growing facilities: (i) aviation for atmospheric research, and (ii) computing. In NCAR's lexicon, "facilities" are not just people operating hardware; they are groups that also provide technical assistance, information, and liaison services, in order that the best possible use may be made of existing resources.

The first facility established by NCAR was the Scientific Balloon Flight Facility, begun in 1961. It operates a balloon flight station at Palestine, Texas, and a secondary base at Page, Arizona, and conducts development projects on balloon materials and design, launching methods, and other aspects of ballooning. It has developed a transponder, by means of which balloons may be accurately tracked by radar, and has designed a standard telemetry system for data handling and in-flight command, making it unnecessary for a scientist with a specific observing job to do "to go out and discover electricity all over again in order to get his data back," as Vincent E. Lally, head of the facility, puts it.

The flight station at Palestine was put in full operation in August 1963; flights are now being made at the rate of some 100 per year. Plans are now ready for the construction of an aluminum inflation and launch shelter 140 feet (42 meters) high. This, when completed, will double the efficiency of the station, save thousands of scientific man-hours each year, and reduce damage to balloons, waste of helium, and ulcers! The aim of the facility, in short, is to convert ballooning from an art to a technologically reliable method of scientific experimentation. The road to this important goal is a rocky one, but this is precisely why NCAR should go down it.

Because of well-established requirements of outside scientists for time on high-speed, large-capacity computers, NCAR moved last July to create a joint-use computing facility. The machine currently in use is a Control Data Corporation Model 3600, and the computing staff numbers 24. Because an increase in the demand for computing time, on the part of the NCAR staff and outside users, is anticipated, NCAR expects to lease a much larger machine, a CDC 6600, and to double the computing staff over the next year and a half.

Research from Airplanes

One of the major problems faced by workers in the atmospheric sciences has always been the nonavailability of suitable airplanes equipped with proper instrumentation and data-handling systems. Thus, provision of research planes was foreseen in the 1959 report as a major role for NCAR. However, NCAR has felt its way carefully in this field. Our role, as we saw it, was to initiate liaison, information, and technical services and to defer the build-up of airplane operations until the extent to which such planes were already available to atmospheric researchers could be determined and NCAR's role could be well defined.

NCAR now has one airplane—a Queen Air 80, a two-engine plane with somewhat higher performance characteristics than the light planes readily available to the individual university scientist. It is used mainly in support of NCAR programs, but a significant percentage of its time is available to scientists in the universities.

In addition, we have initiated the liaison, information, and technical services mentioned above. It is our hope that availability of the services of a permanent group of engineers and flight personnel with experience in atmospheric experiments will relieve the scientists of much detailed technical work and increase the chances of experimental success.

We expect to acquire, within the next year or so, two additional planes, in order to serve more university research projects. According to the report of a national survey group (5), NCAR planes should have a performance capability between that of the very light planes readily available to university scientists and that of the heavier aircraft operated for atmospheric research by such agencies as the U.S. Weather Bureau and the Air Force Cambridge Reseach Laboratories.

Screening New Ideas

There is no dearth of ideas, on the part of atmospheric scientists, about the kind of facilities NCAR should develop. Among those proposed are a versatile atmospheric simulation chamber large enough to avoid wall effects, and sophisticated systems for field observation on a smaller-than-synoptic scale.

But before any such proposal is adopted it must be rigorously studied. A national ad-hoc survey group is organized, composed mainly of non-NCAR scientists with special interests and knowledge in the field in question. It is the survey group's task to determine whether or not the proposed facility is needed, and to make recommendations as to how (and possibly by whom) it should be developed. Only when a survey group has made an urgent recommendation, and when staff studies show (i) that establishment of the facility is feasible, and (ii) that no other agency or institution is in a position to fill the need—only then does NCAR move to create the facility.

Such caution is essential. Funds for atmospheric research will always be limited and must be wisely expended. Only real needs, widely justified, can be met; only critically needed tools can be developed. This is true on a national scale and doubly true for a single research laboratory.

A recent series of NCAR-sponsored discussions is leading toward development of a facility under auspices other than those of NCAR. For several years, cloud physicists and atmospheric chemists have looked upon the island of Hawaii as a near-ideal outdoor laboratory for the investigation of orographic effects and of the precipitation process in general. As a result of the interest generated by the recent discussions, the University of Hawaii and its Institute of Geophysics are taking the lead in developing such a facility. The National Center for Atmospheric Research will assist in procuring, modifying, and installing radars, portable laboratories, power supplies, and communications equipment, but administration, scientific control, and overall planning responsibility will rest with the University of Hawaii. It is expected that the facility will be ready for use next summer for an observing project sponsored by the U.S.–Japan Committee on Scientific Cooperation.

No Sanctuary

The growth of NCAR (it now has approximately 335 full-time employees, including long-term visitors) has come during the post-Sputnik years—a period in which the scientist's role in American society, the manner in which he is supported, and the criteria by which his work is judged have been critically reexamined. The creation of NCAR is a case study of problems and solutions typical of this period. It is the study of an attempt to forge new and more effective methods of interuniversity cooperation, and to use federal funds creatively and efficiently to further basic research. It is the study of a facility which is of great interest to other federal agencies whose efforts it must aid and complement and to many individuals in public life who see how badly the nation and the world need whatever practical benefits such a center can provide. In short, it is a study of basic research deprived of whatever sanctuary it ever had, forced to do its work amid social, economic, and political pressures, both national and international.

This loss of sanctuary is not cause for regret; the pressures only give added evidence of the critical importance of the undertaking. Nonetheless, the tensions involved are obvious and inevitable. This makes the support NCAR has received during its embryo years all the more heartening. The support has come from a group of creative universities with able trustees; from university scientists who have taken it on faith that NCAR would not rob the universities of funds or faculty; from the National Academy of Sciences and the government agencies involved in the atmospheric sciences; from people who are willing to gamble on a new idea in a realm of science having social and economic implications of great urgency.

From the outset the National Science Foundation has been our partner. Under the leadership of Alan Waterman and Leland Haworth, NSF has been steadfast in its support, despite the many difficulties involved in direct sponsorship of a private laboratory, and steadfast in its belief that the Center's success was essential to progress in the atmospheric sciences.

It is my firm conviction—one which is, I believe, increasingly shared by others—that the atmospheric sciences face as great a challenge and hold as great a promise of practical benefit as any scientific discipline. The precise nature or timetable of future accomplishments cannot be predicted, but the progress of the past 20 years justifies the new-found optimism.

References and Notes

1. "Research and Education in Meteorology," an interim report of the Committee on Meteorology to the National Academy of Sciences–National Research Council, Washington, D.C., 25 January 1958.
2. "Preliminary Plans for a National Institute for Atmospheric Research," prepared for the National Science Foundation under grant G 5807 (second progress report of the University Committee on Atmospheric Research, February 1959).
3. The 14 original member universities are as follows: University of Arizona, University of California, University of Chicago, Cornell University, Florida State University, Johns Hopkins University, Massachusetts Institute of Technology, University of Michigan, New York University, Pennsylvania State University, Saint Louis University, Texas A & M, University of Washington, and University of Wisconsin. The trustees-at-large are William S. Jackson, Denver, Colorado; Paul E. Klopsteg, Glenview, Illinois; Robert L. Stearns, Denver, Colorado; and Fred L. Whipple, Cambridge, Massachusetts (there are two vacancies at present).
4. The five additional universities are as follows: University of Alaska; Colorado State University; University of Colorado; University of Texas; and University of Utah.
5. "An Aviation Research Facility for the Atmospheric Sciences" (Report of the NCAR National Aircraft Facility Survey Group), *NCAR Technical Note 64-1* (1964).