Abstract

The National Center for Atmospheric Research (NCAR) has a responsibility for enhancing and assisting the national university-based atmospheric research effort. This responsibility is met partly by programs of research at NCAR that involve cooperation with universities. In these, many visitor and postdoctoral fellows are involved. NCAR also develops and makes available to university scientists special facilities and instrumentation systems that are needed to attack critical problems. These facilities include supercomputers, instrumented aircraft, Doppler radars, and special computer programs such as the NCAR Community Climate Model. This article surveys the broad range of NCAR-university interactions and NCAR services, and addresses the question: Are these programs appropriate and adequate in assisting the universities in their atmospheric research and education efforts?

1. Introduction

During the past year we have been making a comprehensive survey of our interactions with the universities to assess whether we are meeting the substantial responsibilities we owe them according to our chartered mission. The National Science Foundation's (NSF) principal mission is to sponsor basic research, mostly at universities. NCAR, in turn, bears a responsibility for enhancing and assisting the university-based atmospheric research effort through a vigorous research program that interacts with the university community, and through the provision of joint-use facilities.

The "Blue Book," which served as the original blueprint for NCAR in 1959, reflected as follows on the proposed new Institute:

The Institute should be concerned exclusively with basic research . . . [It] should have, in addition to meteorologists, physicists, mathematicians, chemists, and engineers . . .

The Institute will complement the work of the universities. The Institute will strengthen the alliance between teaching and research by assisting universities in meeting their requirements for large research facilities.

It is expected that graduate thesis research would be pursued at the Institute. Opportunities for postdoctoral research study may be extended to promising young men [sic; and now, of course, women as well]. One of the principal justifications for establishing the Institute is to place at the disposal of scientists the array of powerful research tools required to carry out the investigation of the atmosphere.

The facilities of the Institute are to be available on an equal basis to qualified scientists without regard to institutional or organizational affiliation.

Many of the fundamental problems of the atmosphere are not likely to be solved without sustained effort.

These were NCAR's purposes, according to the founding fathers. What does NCAR look like now? The current contract between NSF and the University Corporation for Atmospheric Research (UCAR) specifies two primary missions for UCAR's operation of NCAR. UCAR has governed NCAR under NSF contract since NCAR's founding and now represents the interests of 54 universities through university Members' Representatives and a smaller Board of Trustees. The statement of mission for NCAR included in our contract with NSF coincides with that formulated by the UCAR Board and has been in effect, with minor alterations, throughout NCAR's history. The missions are:

1) . . . Initiate, plan, and conduct a broad-based research program in the atmospheric sciences that will contribute to increased knowledge and understanding within the atmospheric sciences. The selection of programs will be based upon their scientific relevance and importance and often upon the need for long-term, large-scale coordinated effort among atmospheric scientists and need for complex facilities and logistic support which makes such programs beyond the scope of individual universities.

2) Identify the needs of the scientific community for facilities required for research in the atmospheric sciences and related areas; develop and maintain these facilities at the forefront of technology; and make available these facilities in support of the scientific community programs.

A third responsibility, tantamount nearly to a "mission" and seen as beneficial to the first two, resides directly in our contract with NSF:

3) . . . Engage in educational programs in the atmospheric sciences as may be appropriate to the effective pursuit of assisting and complementing the scientific effort of the community.
In reviewing our activities and evaluating them against the prescriptions of the Blue Book and our mission statements, we are led to a number of key questions. Among them: Are NCAR's resources appropriately allocated among university and NCAR programs, and joint programs in which we work together? Does NCAR have the appropriate priorities among the things it does for and with universities? Should any activity receive greater emphasis? The purpose of this presentation is to allow the university community to make judgments on these questions. Let's review the principal areas where NCAR interacts with universities.

2.Mission 1: A strong research program

NCAR's research program recognizes a necessarily broad definition of "atmosphere," extending from inside the sun to the bottom of the ocean. Both the design of our research program and our organization into five research divisions facilitate studying the atmosphere to its extremities, so defined.

The Atmospheric Chemistry Division, led by Ralph J. Cicerone, is developing a panoply of new instruments for measuring atmospheric trace gases. The division is also studying bioemissions of gases into the atmosphere, acid rain chemistry, homogeneous gas phase chemistry in the troposphere, and stratospheric concentration of O₃, H₂O, and other molecules from satellite measurements.

The High Altitude Observatory, under Robert M. MacQueen, studies the solar interior, solar magnetic fields, the solar corona, or outer atmosphere of the sun, and related topics. The Observatory uses NASA satellite platforms like the Solar Maximum Mission (SMM) to study the corona. An important new area of both experimental and theoretical study is the sun's variability.

The Convective Storms Division, under Edward J. Zipser, plans and carries out large field programs to understand convective storms. They do much of the data reduction and data analysis from these field programs, making the data sets available to all participants and applying them to their own research on convective storm processes.

The Advanced Study Program, under John Firor, administers most of NCAR's visitor programs and, through its Environmental and Societal Impacts Group, studies the impacts of weather and climate on people.

To review progress in each of these areas with an eye to the ways in which we interact with the universities, it will be instructive to begin with mention of several major field programs. Such programs, involving collaboration with many organizations, are near the heart of NCAR's work and have involved us in planning, management, scientific leadership, and facility support (See Fig. 1). They have, in the last 10 years, given cohesiveness to atmospheric science, both in vision and in practical achievement.

a. Cloud and mesoscale research

Over the past decade several major field programs, together with improvements in observational technology and advances in theory and modeling, have produced significant new knowledge of convective clouds. A current knowledge of these systems is sufficient for applied research to yield improved predictions and warnings over the next few years. But the greatest improvements in the operational weather services will come only after extensive fundamental research is carried out.

The largest single assault on the complexities of convective storms has been in CCOPE—the Cooperative Convective Precipitation Experiment—carried out in the vicinity of Miles City, Montana in spring and summer 1981, and jointly sponsored by NSF and the Bureau of Reclamation. Involving 16 universities, 15 other research groups from the United States and abroad, and four federal agencies, CCOPE was the most extensive field program ever devoted to the study of convective clouds. To probe cloud and storm development from their early stages through maturity and decay, the project used seven Doppler radars, 125 ground stations, and 14 instrumented aircraft. Coordinating the research—particularly managing the aircraft in flight—was both tricky and involved, and NCAR developed special techniques for accomplishing it. Fig. 2 shows a typical plan of attack by several participating aircraft.

The idea was to learn all one could about single, isolated, cumulus clouds. How do they get started? Can one identify a pre-existing convergence? Does High Plains precipitation always start as ice? How does ice growth start quickly and what are the ice-formation processes? Where does entrainment take place? What controls a storm's speed and direction of motion? Why do some clouds grow big and produce severe weather? CCOPE's experiments were designed to answer these and other questions. The participating groups will have enough data to keep them busy for several years, and the scientific yield will be great. We know already from CCOPE data that there is a lot of entrainment of dry air at the top of a growing cumulus cloud. We can now measure every term in the water balance equation and judge how well the balance works (see Fig. 3). This is being done with CCOPE data.

NCAR led CCOPE's planning activities over a two-year period, provided much of the major equipment used in the field, and processed all the radar, aircraft, and Portable Automated Mesonet (PAM) data, making them available to all interested researchers. NCAR has also hosted workshops to interpret field results and to apply them to CCOPE's studies. Modeling and field experiments on the cloud scale have yielded new insights into processes that influence the forma-
tion and intensity of rain, hail, and wind generated by thunderstorms. These include boundary-layer processes, entrainment of dry environmental air into the cloud, microphysical processes that enlarge cloud particles to precipitation sizes, and the dynamic structure of the storm throughout its life cycle. Note-
worthy among our university collaborations is a conceptual model of a hailstorm synthesized from field data by Brant Foote of our Convective Storms Division and John Latham of the University of Manchester.

The task before the community now is to investigate all scales of motion between the cloud scale and the synoptic scale, and the interactions of these scales with both larger and smaller scales. Technological limitations have prevented such a multi-scale approach until now. Great improvements in field observations, aircraft instrumentation, remote sensing from satellites and from the ground, and in data-handling technology hold the key to a better understanding of scale interactions and better short-term weather predictions and warnings that will characterize the weather services of the future.

b. Storm

The next major field program in mesoscale meteorology is the initial project of the national Stormscale Operational and Research Meteorology (STORM) program, whose objectives are: to enable meteorologists (both public and private) to observe and predict the occurrence of small-scale weather phenomena with substantially improved timeliness, accuracy, and communications efficiency; and to apply these new abilities to protecting the public, serving the economy, and meeting defense requirements. UCAR has organized the overall STORM planning effort, and during 1983 NCAR and over 100 university scientists developed the preliminary plan for
the first of three field experiments. This first phase is called Storm-Central. It will be the largest mesoscale field experiment ever done, and will involve most of the mesoscale scientists and relevant field equipment in the United States. NCAR will be a major player, both in research and in providing field and computational facilities. Fig. 4 shows a proposed layout of the field project. The meso alpha-scale network (largest box) will cover a $2000 \times 2000 \text{ km}^2$, with upper-air measurements every 200 km. The meso (beta-scale) network will cover about $400 \times 400 \text{ km}^2$, with upper-air measurements every 50 km and about 14 strategically placed Doppler radars.

c. Joint Airport Weather Study (JAWS)

Another mesoscale meteorological experiment carried out in recent years is JAWS. It has produced significant information on transient events called microbursts and has implicated them in a significant number of aircraft crashes. The July 1982 crash of a Pan American Airways jetliner in New Orleans was a tragic case in point.

JAWS's precursor was the work by Theodore Fujita of the University of Chicago, whose Project NIMROD in 1978 established the existence of violent, small-scale wind features near the ground that can severely threaten aircraft during landing or takeoff. Microbursts occur not only in the vicinity of thunderstorms, but also in the presence of harmless-looking clouds; for example, they can occur where rain is evaporating under a convective cloud. The scale of these events is on the order of 2 km—shorter than a jet runway. Fig. 5 shows the potentially lethal sequence of events that begins when an airplane, coming in on a proper glide path, first encounters the headwind from a microburst outflow. Sensing the headwind and the added lift it gives, the pilot noses down or reduces power to avoid rising above the glide path. But as tailwinds replace headwinds, the aircraft loses lift, and the pilot may not be able to increase power in time to keep the plane from striking the ground short of the runway. On takeoff, a plane experiences rapid lift from strong headwinds, followed by tailwinds and a loss of lift that can drive it back into the ground.

The JAWS field program, carried out in summer 1983 in and around Denver's Stapleton Airport, had major support from NSF, the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). NCAR managed the field project and provided three Doppler radars, 25 PAMs, and two research aircraft. Fujita, along with John McCarthy and James Wilson of NCAR, were principal investigators, and scientists from the University of Wyoming, the University of Tennessee, Massachusetts Institute of Technology, and Colorado State University took part.

It is clear that microbursts are small, short-lived, and potentially lethal. JAWS showed they are plentiful as well. The urgency of these findings prompted us to enter the domain of applied research—contrary to our usual policy—and work to acquaint airlines and crews with microbursts and to help FAA deal with them. McCarthy helped to make a training film explaining microbursts and NCAR staff helped prepare a computer program for flight simulators to help train pilots to handle them. We are helping to design radar detection systems that could be used at major airports.

A recent near-crash of a United Airlines 727 at Stapleton Airport involved a plane that took off directly into a microburst. At the end of the runway the plane was at 10 feet altitude instead of the usual 1500 feet. The plane's second officer, who had taken pilot training on microbursts, was able to handle the plane in the best way to react to the emergency and avoid a crash.

d. Atmospheric chemistry

Atmospheric chemistry has experienced a revolution during the past decade. Surprising information has come to light on constituents such as chlorofluoromethanes and carbon dioxide, on the role of oxidants in acid rain, and on interactions between the atmosphere and biosphere, to name only a few.
We are still very much in an age of discovery rather than of
detailed synthesis.

During the past decade atmospheric chemists have come
under heavy pressure to provide information to decision-
makers on local, regional, and global air quality, and on
climate-related issues. While eager to comply to the extent
possible, chemists have had to persuade science administra-
tors, planners, and decision-makers that truly reliable infor-
mation on which to base momentous economic decisions must
await a more basic understanding of atmospheric chemistry.
Moreover, the full effects of human activity—from industrial
emissions and agricultural pollutants to massive changes in
land use—must likewise await a better understanding of the
atmosphere's composition, its variations in time and space,
and natural influences upon it.

Quite appropriately, a strong push for a coordinated na-
tional program on global tropospheric chemistry has resulted.
Laboratory and modeling work must increase, but a near-
term task of far greater difficulty and expense will be to obtain
adequate measurements of the chemistry of the global tropo-
sphere, including space and time variations. The task will re-
quire the development of a whole generation of measurement
instruments and techniques, as well as the provision of long-
range, heavy-load-capacity aircraft. Equally important is
close contact with biologists, soil scientists, and oceanog-
raphers to assist in illuminating biospheric influences on the
global troposphere. We foresee a large and fruitful area for
interacting with university colleagues.

e. APEX

Regional air quality must also be the subject of fundamental
studies, and one of the most crucial of those must be acid pre-
cipitation. The Acid Precipitation Experiment (APEX), sup-
ported by NSF and the Environmental Protection Agency
(EPA), was designed to further our understanding of how,
where, and when SO$_2$ and the oxides of nitrogen are converted
into acid rain. Scientists from 11 institutions participated in
planning and executing the experiment. The 1979 field mea-
surements, directed by Allan Lazrus of NCAR and involving
many university scientists, investigated sulfuric acid forma-
tion during a springtime warm front over Ohio (see Fig. 6).

The APEX measurements showed little sulfuric acid up-
wind from the cloudy area but detected it in cloud droplets
too small to fall as raindrops. The sulfuric acid evidently
formed in the cloud, almost certainly through aqueous chem-
ical processes. In our current view hydrogen peroxide is the
most likely oxidant leading to acid formation. The chemical
path is both exotic and not readily apparent. The scarcity of
H$_2$O$_2$ in the atmosphere may limit the amount of SO$_2$ con-
vertible into sulfuric acid. To find out what actually happens
is an important next step for the community.

To continue its work on the acid rain problem, NCAR has
planned more flights for later in 1984 and has mounted an
even larger effort in modeling. Better instrumentation is
mandatory for field measurements, and we have now de-
veloped a new aqueous instrument to measure H$_2$O$_2$ down
to levels of 0.1 ppb. We still lack instruments that can measure
SO$_2$ levels down to tens of parts per trillion in clean air and
the hydroxyl radical OH down to 1 ppt—its probable level in
clean air.

Our modeling work, part of an EPA-sponsored project, is
under the leadership of Julius Chang. The goal is to develop
an Eulerian grid point regional model that will handle both
meteorology and chemistry—a task that has defied other ef-
forts in the past two or three years. The model will use the
mesoscale meteorological model developed over several years
at Penn State by Richard Anthes, Alfred Blackadar, and
others. Thomas Warner (Penn State) will study a series of
meteorological case-history data sets to help validate the
model as a part of the project.

The Anthes-Blackadar model has already been used for
several years and has been reasonably well validated. It was
recently used to study a storm of 10 April 1979 that produced
a tornado at Wichita Falls. The model did a good job of
showing all the major mesoscale features of the storm. It also
replicated the dry-line structure in western Texas, the motion
of moist warm air off the Gulf of Mexico, and a region of up-
ward-moving air near the Oklahoma border quite close to the
site of the actual severe weather.

The chemical model being developed at NCAR will use
both gas- and liquid-phase chemistry. It will include about 40
chemical species and as many as 100 reactions among them.
It will be validated with field data on SO$_2$, NO$_x$, H$_2$SO$_4$,
HNO$_3$, and various oxidants and other chemical species. EPA
sees a variety of uses for the model, possibly including regula-
tion. We hope the project will also—in a few years—produce
a community chemistry model analogous to our community
climate model, on which researchers can test new hypotheses
and explore new ideas.

The foregoing projects, and others, have distinguished the
work of our Atmospheric Chemistry Division (ACD) and
brought it into extensive collaboration with university col-
leagues. The full spectrum of the division's work has given it
a major role in field and laboratory work on regional air
quality, the exploration of stratospheric chemistry, the design
of trace-gas measuring equipment, chemical modeling, and the
determination of natural influences on the atmosphere's
composition. It has also involved ACD in forging links to
relevant neighboring disciplines, particularly atmospheric
dynamics, and in planning and leading major collaborative
field projects.

f. Global Tropospheric Chemistry Program

Over the next five years ACD will continue its important
work in stratospheric chemistry, regional air quality, and
acid rain, but will increase its emphasis on the global troposphere. Compelling but basic questions prompt such a shift. For example: 1) What factors make the atmospheric composition the way it is in the first place? 2) Why are certain trace-gas concentrations increasing (e.g., CH$_4$, N$_2$O, CO)? and 3) How important are natural biological emissions in influencing atmospheric composition (e.g., hydrocarbons, sulfur compounds, ammonia, halogens)?

NCAR has been active in pushing for a national program to obtain adequate observations of the chemistry of the global troposphere. After an initial planning effort led by Ralph Cicerone (NCAR) and James Anderson (Harvard), a National Academy of Sciences (NAS) panel studied the program further. The NAS Report was released in October 1984. This is an area of greatest importance to the nation. The projected Global Tropospheric Chemistry Program would be a major effort over a full decade, and would involve NCAR deeply. Probable major elements of the program would be surveys of biological and oceanic sources of gases, wet and dry removal processes, global distribution of gases and aerosols, in situ chemical reactions, and tests of photochemical theories. NCAR is already developing several instruments useful to such a program.

g. Climate

The past decade has also seen a dramatic increase in our understanding of climate and progress in modeling climate. Particularly important developments across the community are: 1) Climate models now simulate present and past climates with enough realism to give us confidence in examining the quantitative effects of various internal and external influences; 2) There is increased understanding of the physical processes that determine climate in nature and a far better understanding of how the models simulate climate—that is, the physical and numerical aspects of climate models and their interrelationships; 3) There has been substantial expansion in the development and use of global data sets, including those from the field program of the Global Weather Experiment of 1979 and from paleoclimate studies. These have led to many insights in defining and analyzing climate; and 4) There has been an increase in the theoretical understanding of global atmospheric dynamics, leading to new insights into problems ranging from the theoretical limits of predictability to improved methods of initialization.

h. Community Climate Model

The overall objective of NCAR's climate research is to understand the physical and dynamical processes that govern the behavior of the global atmosphere on time scales ranging from a few days to millions of years. Given the state of the science, a logical strategy for NCAR is to continue to develop climate models, incorporating an increasing number of processes, and to make them accessible for studies of the limits of predictability, climate formation and change, and the impacts of human activity, the most severe of which is nuclear war. Several of our scientific programs are developing general-use “community” models. These large, complicated numerical models are well-documented and user-friendly so that they can be used easily by many scientists. We make them available

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The process is now being used operationally by the National Weather Service.

i. MONEX

The Monsoon Experiment (MONEX) was carried out in 1979 over the Indian Ocean and adjacent countries. NCAR was deeply involved in Summer MONEX—the study of moist air flow off the Indian Ocean onto the land mass. The resultant monsoon rains are the driving force of Indian agriculture. The interannual variability of the monsoonal flow is a matter of considerable interest in current climate research.

When MONEX was in the final planning stages in 1976–77, a U.S. MONEX Office was established at NCAR with Joachim Kuettner as its head. Kuettner was also on the World Meteorological Organization (WMO) and U.S. planning committees for MONEX. With an Indian counterpart he shared the job of scientific leadership of the summer field program.

The NCAR Electra was one of the three U.S. aircraft that flew long flights (totaling 460 hours) over the Indian Ocean to measure the flow conditions. NCAR field personnel helped carry out the initial site surveys to locate operational centers roughly in the middle of areas corresponding to the three monsoon stages under study. The choices were Bombay, Calcutta, and Riyadh, Saudi Arabia.

NCAR made all arrangements for the nearly 200 scientific and support staff to travel to and from the area of the field experiment; for hotels, ground transportation, and medical care for field personnel; for the operations center to support the program; and for aircraft ramp space, fuel, and maintenance facilities. NCAR also arranged for shipping all equipment, securing customs clearances, and overseeing brokerage activities. We monitored the financial duties of the U.S. government to provide support to the program—including banking and contracting arrangements in India.

The field staff successfully moved the entire operation from Bombay to Calcutta, interrupting the scientific program only a few days. And at the end of the program, the staff reversed all the actions described earlier; securing customs clearance for all aircraft out of India; paying for hotels, equipment, supplies, and salaries for temporary help; shipping equipment back to the United States and securing clearances at both ends; and concluding all financial and contractual arrangements according to Indian regulations.

j. Physical oceanography

The world ocean is an integral component of the climate system and gives climate its long-term “memory.” There is a growing body of scientists across the country who are involved in dynamical studies and modeling of the oceans and in linking new knowledge from that research to the dynamics of the global atmosphere. Indeed, studies of atmospheric and oceanic circulations lead to a cross-fertilization of ideas in general fluid dynamics research.

NCAR’s oceanography program is a modest but crucial element in the national effort. Its staff comprises five Ph.Ds., three other professional staff, and three long-term and four short-term visitors. The group has become nationally prominent in ocean modeling and dynamical studies, with special emphasis on eddy-resolving general circulation models; ocean models with active thermodynamics; process models relating to
to eddy dynamics, scale interactions, and other problems; and air-sea interactions. Coupled with NCAR's large computing resources, the Oceanography Section has helped to create a focus at NCAR for a national effort in physical oceanic modeling, particularly in directions that can lead to realistic, coupled, atmosphere–ocean climate models. However, much work needs to be done in oceanic modeling before the most productive and realistic coupled models will be possible.

NCAR's interactions with the physical oceanographic community have also involved us in planning national and international programs, such as the World Ocean Circulation Experiment, and in the analysis and design of field experiments. The long-term objectives of the national effort are to understand the processes that control the global ocean circulation and to link them to the dynamics of climate.

k. Solar physics

The field of solar physics encompasses studies that range from traditionally astrophysical subjects—the formation of chromospheres, stellar winds, and plasma processes—to solar influences on the terrestrial environment, such as geomagnetic disturbances and climate variability. We stress equally an understanding of the sun as an astrophysical object—an archetype of stellar processes—and, within the terrestrial context, the study of the sun's output, including radiant energy, particles, and fields. The latter provides the basis for understanding changes in the terrestrial system that may prove fundamental in understanding the earth's climate and its variation.

Several discoveries in the past decade have dramatically altered our view of the sun and solar processes: 1) We now recognize that the regular, periodic nature of the solar activity cycle is not immutable; there are known periods when the cycle has varied in amplitude both more and less than in our modern experience; 2) the sun is now known to exhibit variations in luminosity, correlated in the gross sense with the appearance of solar activity; 3) a refined understanding of the processes by which energy and momentum are transmitted through the lower solar atmosphere may free us to discard earlier notions of the mode by which the sun's outer atmosphere is heated; 4) mass ejections—a new manifestation of solar activity—have been identified from space observations and are now the subject of intense study, both for their intrinsic interest and for their potential geomagnetic influences; 5) we now realize that global solar oscillations are present, and that they provide unique clues about the nature of the solar interior and probably stellar interiors in general; 6) the solar magnetic field is now understood to be of paramount importance in transferring mass, energy, momentum, and radiation in the lower solar atmosphere; and 7) our understanding of the structure of the heliosphere has been improved by our ability to determine the nature of the interplanetary medium through new observations, theory, and modeling.

The work of our High Altitude Observatory (HAO) spans this broad spectrum of subjects. In particular, we seek increased understanding of: a) global solar properties that lead to the variable nature of the solar output; b) the coupled physical structure of the solar corona and solar wind; and c) the balance of physical processes in the lower solar atmosphere. All three will raise fundamental questions about the physical processes taking place in the sun's interior and its atmosphere, which extends throughout the interplanetary medium. Some of the leading questions are: Why does the sun have an activity cycle and how does it function? What properties of the sun are modulated by this cycle and why? What are the properties of the solar magnetic field and how does it affect the transport of energy and momentum through the atmospheric layers? Satellites will provide most of the necessary observations and have now substantially—though not entirely—replaced ground observations which began, in HAO's early history, on a 10,000 foot mountain at Climax, Colorado.

l. SMM

The Solar Maximum Mission (SMM) was carried out by a NASA satellite launched in February 1980 and containing a coronagraph-polarimeter experiment initiated by HAO with 13 university scientists as coparticipants. The instrument operated about a year and obtained 30,000 observations of the corona. Planning for the experiment began in 1972, and analysis of the data is still in progress. The purposes of this experiment—now on their way to realization—are to study the properties of transient solar events and their relations to solar flares, and to examine the nature of the active solar corona. Fig. 9 is an SMM photo showing density distribution during a solar event. The SMM satellite went out of operation in the fall of 1980, but shuttle astronauts started it up again in April 1984 using a repair kit developed in part by HAO. We now will get a set of coronal photos near solar minimum to go with the good set near solar max.

m. Eclipse expeditions

Although many solar measurements are now made on satellites, some studies (such as changes in the ionosphere during an eclipse) can still be carried out better by earth-based instruments. HAO scientists have a valuable archive of solar
coronal photographs made during eclipses over a span of 30 years. NCAR has organized and managed eclipse expeditions for NSF for many years. Last year, Karyn Sawyer-Crouch coordinated arrangements for an expedition of scientists from nine universities that observed an eclipse in Indonesia on 11 June 1983. HAO will probably lead an expedition to Borneo or the Philippines in 1988.

n. SOT

HAO is participating in the development of the Solar Optical Telescope (SOT), a meter-size telescope planned for flight aboard the shuttle in 1989 (see Fig. 10). Capable of sub-arcsecond resolution, the SOT will provide observations of small-scale magnetic elements in the solar atmosphere and observe the interaction of radiation and plasma in the solar photosphere. With this high resolution, solar physicists should be able to study in detail the regions where solar flares start and, perhaps for the first time, see the clumping of magnetic fields into small bunches only about 1000 km across. The SOT is expected to produce five trillion bits of data. This amount—approximately the size of NCAR’s total data archive today—will strain our abilities in data-handling and processing. Dick Fisher of HAO has been appointed by NASA to represent the SOT requirements of all solar physicists.

As another project, HAO is starting to develop general magnetohydrodynamics models of the sun and hopes to make them available for general use as community solar models in a few years.

o. Environmental and societal impacts

Atmospheric scientists are being called on increasingly to speculate about future climate changes resulting both from human activities (e.g., increasing CO₂) and from natural causes (e.g., extended droughts, the El Niño). Decision-makers and planners need knowledge about future climatic events in order to plan for unavoidable changes and to intervene in preventable changes. NCAR’s Environmental and Societal Impacts Group (ESIG), a group of about ten within the Advanced Study Program, studies our progress in understanding climatic processes and the possible results of climate changes. The group endeavors to identify where and in what manner climate changes will impact society, and, in the case of human-induced changes, what societal forces are at work to cause them. The newness of this field is evidenced by the fact that despite its modest size, NCAR’s program is regarded as an international leader.

There is no set of recognized methods for assessing climatic impacts, particularly for climate changes of global scale, such as greenhouse warming. A research strategy that has proved effective is to supplement direct studies, such as climate-crop production models, with a variety of case-study projects. Each case study contributes valuable knowledge in its own right and enlarges our repertory of techniques for investigating climate impacts.

The case-study projects fall into three categories: 1) Investigations of how actual forecasts are used, or how hypothetically improved forecasts might be used, to aid various human endeavors; cases of this sort help indicate how climate prediction capabilities could be effectively employed. 2) Translation of up-to-date scientific information for use by actual planners and decision-makers; from such cases we learn to what extent society can use given levels of prediction capability. 3) Study of the impacts of actual or analog climate changes; we have sufficient data on enough examples of recent climate changes (e.g., the six-year drought in the Sahel and the recent, intense, one-year El Niño) to investigate directly how they impact large groups of people under varied circumstances. Other recently observed and well-documented changes, such as the depletion of the Ogallala aquifer, have many of the characteristics of a climate change and can be used as analogs for these investigations. Case studies have the limitation that the events studied are regional rather than global, and are usually of relatively short duration.

p. Interactions with university scientists in science programs

The foregoing discussion, necessarily protracted, has served to illustrate that NCAR’s scientific program is both independently strong and closely tied to university research. Both one-to-one interactions with university colleagues and large community efforts involving many scientists and organizations add fiber to our program and are essential to our accomplishing our research mission. Each year we write a detailed work plan for the next year and send it to NSF as a control document. Our latest plan lists collaborations with 290 non-NCAR scientists anticipated in the coming year. Our collaborators will come from 43 UCAR Member Universities, 21 other U.S. universities, 25 foreign universities, and 17 nonprofit and government laboratories.

q. Joint papers

An ultimate test of scientific interactions is the number and quality of papers jointly authored by NCAR and university scientists. As can be seen in Fig. 11, more than one-third of NCAR’s papers each year are coauthored with one or more scientists at universities or other research institutions. Collaboration with visitors in residence at NCAR, not tallied in Fig. 12, raises the level of total collaboration even higher.

Fig. 10. Solar optical telescope planned for flight aboard space shuttle.
RESEARCH COLLABORATION
Joint Publications

<table>
<thead>
<tr>
<th>Period of Time</th>
<th>Publications</th>
<th>Coauthored</th>
<th>Coauthored as Percent of Total</th>
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<td>January 1977-March 1978</td>
<td>465</td>
<td>159</td>
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</tr>
<tr>
<td>Calendar Year 1983</td>
<td>295</td>
<td>135</td>
<td>45%</td>
</tr>
</tbody>
</table>

Fig. 11. Research collaboration, joint publications.

3. Mission 2: Provide special facilities

NCAR operates several major facilities for use by both NCAR and university scientists. The UCAR-mandated provision of facilities has been an unbroken tradition in NCAR’s history and answers a specification of the founding Blue Book: “One of the principal justifications for establishing the Institute is to place at the disposal of scientists the array of powerful tools required to carry out the investigation of the atmosphere.”

a. Research aviation facility

For 19 years NCAR has provided instrumented aircraft to the research community. Our current fleet includes a Queen Air propeller aircraft, a turboprop King Air, a second King Air leased six months each year from the University of Wyoming, a twin-jet Sabreliner (see Fig. 12), and a four-engine Electra. The Queen Air will soon join another in retirement. Both have been workhorses of our fleet—a distinction now passing to the King Airs. The Electra, which has great range and carrying capacity but is very expensive to fly, has been used principally in large sub-programs of the Global Atmospheric Research Program (GARP)—the Atlantic Tropical Experiment, the Monsoon Experiment, and the Alpine Experiment—and in long-range atmospheric chemistry measurement programs. The Electra has been out of operation for two years, but we are now fitting it with new avionics and a new data system for operations in the Genesis of Atlantic Lows Experiment (GALE), a program led by Peter Hobbs of the University of Washington and scheduled for February 1986.

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Robert A. Duce, University of Rhode Island
David Raymond, New Mexico Institute of Mining and Technology
William A. Cooper, The University of Wyoming
Alan Bandy, Drexel University
John C. Wyngaard, NCAR
Carl Friehle, University of California-Irvine
Julian Shedlovsky, NSF Observer

FOF ADVISORY PANEL MEMBERS
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Edward Zipser, NCAR
Peter Ray, National Severe Storms Laboratory
Arthur Jameson
Harold Orville, South Dakota School of Mines & Technology
Richard M. Schotland, University of Arizona
Richard Dirks, NSF Observer
Julian Shedlovsky, NSF Observer

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Dimitri Mihalas, NCAR
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Peter B. Rhines, Woods Hole Oceanographic Institution
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Lawrence Lee, NSF Observer

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H. Virji, NSF Observer

Fig. 12. NCAR aircraft at Jefferson County Airport (Jeffco) Operations Base.
Panels composed mainly of university scientists (see Fig. 13) advise us on the allocation of resources for all our facilities. Recommendations of the panels are followed in virtually every case. Fig. 14 shows the percentage of aircraft hours flown for university, NCAR, and joint projects over the past six years. University projects dominate except in years when NCAR and university scientists work together in large joint field projects. Purely NCAR projects have consumed a minor fraction of the resource. Funds to fly the Electra must be obtained on a program-by-program basis, while flight hours for the other aircraft are funded centrally.

Fig. 15 shows fewer aircraft hours flown during the past three years. The panel decided about three years ago that acquiring new aircraft and improving the instrumentation and data-handling capabilities of all our aircraft should temporarily take precedence over maintaining a high level of flight hours. We purchased the King Air in 1982 and are improving all airborne instrumentation. In 1983 we started to increase the available flight hours but they remain at a level that both the community and we believe is too low. Our intent is to roughly double the annual allocation over the next decade.

b. Field Observing Facility

NCAR’s Field Observing Facility has developed two outstanding new observing capabilities in recent years—the Doppler radar and the PAM II ground-based observing network (Fig. 16). Supplementing them is a Research Data Support System, which has made data handling much easier and more effective. FOF now has three Doppler radars that can be used for field programs, including the recently improved 10-cm CP2 radar. Frequently able to get signals from the clear air in the boundary layer, the CP2 may be the best Doppler radar in the world for field meteorological measurements.

Fig. 17 shows the major programs supported by FOF over the past seven years. Allocations of resources to all these programs are made on the advice of the FOF Advisory Panel, as previously explained.

We now have 50 PAM IIIs in use. Because they communicate by satellite, they do not have to be in line of sight, nor must they all be used in one experiment. Eight units assisted the Weather Service at the 1984 Summer Olympics in Los Angeles while others were in use simultaneously in scientific experiments.

### PERCENT OF TOTAL RESEARCH HOURS FLOWN BY CATEGORY OF USER

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<th>Year</th>
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<th>NCAR</th>
<th>Joint</th>
<th>Other</th>
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<td>61%</td>
<td>1%</td>
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<tr>
<td>FY 1983</td>
<td>54%</td>
<td>12%</td>
<td>21%</td>
<td>13%</td>
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</table>

Fig. 14. Percent of total research hours flown by category of user.
The Computing Division has a history of making available to the community state-of-the-art hardware and services. We are now upgrading to meet the demands of the 1980s, especially in handling the models and large data sets that are so central to atmospheric research. Last year we added a second CRAY-1A, nearly doubling our computing power. The facility is again nearly saturated, however, because the CRAY-1A lacks the brute capacity to accomplish crucial modeling tasks. Not even two CRAY-1As can model an ocean basin, combining reasonably realistic mesoscale eddies (with scales of tens of kilometers) with an ocean basin size regime whose scale is many thousands of kilometers.

We have spent two years researching and writing a justification for a Class VII or Advanced Vector Computer (AVC). At the heart of this document are six sections discussing the needs of various subdisciplines, written by the following nationally known scientists: Peter Rhines (Woods Hole), oceanography; Julius Chang (Livermore) and Michael McElroy (Harvard), atmospheric chemistry; Richard Anthes (NCAR) and William Cotton (Colorado State), mesoscale meteorology; and Peter Gilman and Dimitri Mihalas (NCAR), solar physics.

The AVC should have about a factor of 10 more throughput than the CRAY-1As we have now; its speed will be about 500 million instructions per second and its memory will hold 10 million words or more. The initial funding for the AVC is in the president's budget for FY 1985. If all goes well, the AVC should arrive at NCAR in 1986. We also are working to upgrade the NCAR Mass Store system to remove bottlenecks in data storage and speed of access. We expect to replace our aging Terabit Memory with a new Mass Store system starting in 1985.

d. New facility development

To provide university scientists with access to the NCAR computer without their having to pay long-distance phone bills, NCAR has joined UNINET, a communication network that links many sites together by telephone lines. We hope to upgrade its presently limited bandwidth (using 1200-baud phone lines) with a higher bandwidth; still a further improvement would be satellite communication, and this, too, is under study.

UCAR policy prescribes an allocation of at least 40% of the total computer resource to university users, 20% to joint university-NCAR projects, the remaining 40% to NCAR projects. (The actual figures for 1983 were 42, 16, and 42%, respectively.) For university use, an advisory panel (see Fig. 14) recommends allocations after reviewing plans and proposals.

The computing division is a “full-service” group, offering a broad array of user services. Unique among these is the Data Support Group, headed by Roy Jenne, who is regarded by many as a national treasure. His group has built a large, computer-readable archive of data sets, patiently assembled from long-hidden sources at the National Climatic Center in Asheville and various other—often obscure—locations. The next big addition to our archive will be a major historical data set from marine ship observations. The set, to be ready for use in a few months, contains seven million observations of more than a hundred years of sea-surface temperature, wind speed and direction, squall conditions, cloud conditions, and other measurements. The computing division also assists all users through its extensive consulting service. Perplexed new users and old timers whose programs occasionally falter are taken equally in tow.

Fig. 17. Summary of FOF field support to universities.

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Program Name</th>
<th>Investigator</th>
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<tr>
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<td>Boundary Layer Expt</td>
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<td></td>
<td>Socorro</td>
<td>Win and Moore</td>
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<td></td>
<td></td>
<td>Roy</td>
<td>NSSL</td>
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<td>1982</td>
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<td>Hobbs</td>
<td>U. of Washington</td>
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<td></td>
<td>Sierra</td>
<td>Marowitz</td>
<td>U. of Wyoming</td>
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<td>JAWS</td>
<td>Fujita</td>
<td>U. of Chicago</td>
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<tr>
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<td>Guldsen</td>
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<tr>
<td></td>
<td>SPACE</td>
<td>Cotton/Grant</td>
<td>Colorado State U.</td>
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</tbody>
</table>

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e. Super PAM

Working with Bernard Silverman and the Bureau of Reclamation, we have developed the second-generation portable automated mesonet (PAM), already described above. We are continuing to improve PAM by developing new instruments to add to the standard meteorological sensors. We hope to be able to measure fluxes of heat or moisture, and perhaps certain chemical species, either by gradient or eddy-correlation techniques. We would then be able to measure the pH of rain as well.

f. Safesonde

Among the most important measurements taken routinely by the National Weather Service are upper-air winds, temperature, and humidity, using balloon-borne sounding systems. This system, which uses small packages of sensors and radar tracking of the balloon’s ascent to the stratosphere, was designed in 1940 and is now obsolete and hard to maintain. For our studies of cumulus clouds we need greater accuracy in balloon tracking and better sensors than the present system affords. Our newly developed upper-air sounding system, called Safesonde, can be ingested by a jet
airplane engine without damaging the engine. It is now being tested against the very high-accuracy tracking radar at Wallops Island. Developed by Vincent Lally and his coworkers in NCAR’s Global Atmospheric Measurements Program, Safesonde promises to give us an inexpensive, easy-to-operate upper-air sounding system. We plan to have six Safesondes available for the GALE field program in January 1986. The system is certain to become an essential tool for the national STORM program and for any other mesoscale project requiring coverage of areas as large as one or several states.

g. Airborne Doppler radar

We are now working on a new airborne Doppler radar. Cooperative tests with NOAA on their P3 aircraft show great promise. It seems possible to combine data from airborne and ground-based Dopplers for dual-Doppler studies of the same target storms. It also seems possible to fly an “L”-shaped pattern around a storm, securing dual-Doppler measurements from the two legs of the flight pattern (see Fig. 18). Airborne Doppler is a high-priority need for the STORM Central project, and we hope to mount one on one NCAR plane by 1988.

h. The Stokes Polarimeter III

HAO, in collaboration with the University of Sydney and the National Solar Observatory, is designing and will start next year to build a new optical instrument to better measure the solar magnetic field. It will measure the longitudinal field by Zeeman splitting and the total vector magnetic field by measuring all four of the Stokes parameters. Existing Stokes polarimeters average the field over a distance of 7000 km. The new instrument is expected to cut this to 1000 km. The Stokes III should allow us to make the first studies of the three-dimensional structure of the clumping of the general solar field as it is swept into bundles less than 1000 km across by the sun’s convective motions. Further insight into the clumping effect will come from observations by SOT, discussed earlier. Current plans call for Stokes III to be installed at Sacramento Peak in 1986 as a facility available for use by qualified university scientists.

### TUNABLE DIODE LASER SYSTEM

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<thead>
<tr>
<th>Molecule</th>
<th>Calculated Minimum Detectable (ppb)</th>
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<tr>
<td>SO₂</td>
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</tr>
<tr>
<td>HNO₃</td>
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<tr>
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<td>0.3</td>
</tr>
<tr>
<td>NO</td>
<td>0.2</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Fig. 19. Tunable diode laser system.

i. Cloud physics instruments

Two years ago Jack Warner joined NCAR to help develop new airborne cloud physics instrumentation. Greater accuracy is needed, for example, in measuring liquid water in clouds, the characteristics of small particles, and in-cloud temperatures. Warner is working on a clever system for getting a three-dimensional picture of a cloud’s liquid water. Multiple scans of passive microwave radiometers through the cloud are combined tomographically to portray the three-dimensional water distribution. Tests of the system in two dimensions look promising. Another development is an infrared CO₂ radiometer able to measure in-cloud temperatures to 0.2°C. It is not subject to wetting, which degrades the accuracy of most conventional sensors.

j. Chemistry instrumentation

NCAR is working on several new instruments to measure chemical species at very low concentrations. One of the most promising is the tunable diode laser, a solid-state laser allowing rapid electronic changes of its wavelength. Setting the frequency on an absorption line of the molecule to be studied and then changing rapidly from on-line to off-line gives a measure of the amount of absorption and the concentrations of the molecules. Fig. 19 shows the concentrations of six molecules that should be measurable. The instrument performed well in flights to measure CO, and its chief developer, William Mankin, will fly a modified system to measure SO₂ in a few months. We hope to have a tunable diode laser available for the NCAR aircraft in a few years.

### Educational programs

NCAR shares with the universities a need for capable new generations of atmospheric scientists and a responsibility to assist in their maturing. Several programs at NCAR are directed to that end. They include postdoctoral appointments and graduate research assistantships (GRA), both run by the Advanced Study Program (ASP); graduate research fellowships and a summer undergraduate program offered by HAO; and sponsorship of both junior- and senior-level visitors by all NCAR divisions.
Through its postdoctoral program ASP provides new Ph.D.s flexible opportunities for interacting with NCAR's research programs in ways that can lead to long-term associations between scientists in the universities and at NCAR. We ask the postdoc applicants to submit plans for their proposed research, but once here, they are free to explore new—perhaps entirely new—directions. As many as one-third of our postdocs significantly change the course of their research programs during their first year. Two, for example, jumped into the new problem of the nuclear winter when it became exciting and controversial.

Over half the postdocs stay a second year. Their extensions must be approved by ASP and by the divisions in which they are working. Most postdocs tackle new research problems during their second years. Postdoc appointments numbered 25 in 1983–84 and 15 to 17 for the four years prior to that.

Our Graduate Research Assistantship Program, begun in the 1978–1979 academic year, assists graduate students whose thesis advisors include both an NCAR scientist and a professor at the home university. NCAR offers stipends equivalent to half-time appointments for students to spend one or more years here. We granted seven GRAs the first year (1978) and will grant 10 to 12 in 1984–85. The rapid growth of interest in this program has overwhelmed us with applications; we hope to accommodate more appointees in coming years. So far, 17 GRAs have obtained Ph.D.s and 13 are still in Ph.D. programs.

Fig. 20 shows the numbers of short- and long-term scientific visitors to NCAR over the past six years. Since 1978 the sum of the two has been at or above 100 each year. The scientific visitor program is of inestimable value to us, bringing fresh viewpoints to our work and fostering the scientific collaboration that is so essential to progress on many of the central problems of our science.

For the past three years NCAR has had a modest summer program to provide special access to an atmospheric research laboratory for women and minority students. Each summer six or eight undergraduates come to NCAR to work on problems with NCAR scientists. At summer’s end they present their research results in seminars and technical papers. We hope that the best of these students can be recruited into the atmospheric sciences; it is too early in the program’s history to know how successful the recruiting effort will be.

Following its last review of ASP, a panel of the UCAR Scientific Programs Evaluation Committee recommended that we restore a senior postdoctoral fellowship program that was phased out several years ago. This program supplemented the funding of individual senior scientists whose visits to NCAR’s research divisions are included in the tabulations of Fig. 20. We are examining a renewal of this effort along lines that will ensure the greatest productivity for both the visitor and ASP.

c. Summer colloquium

Another reinstatement, already accomplished, is the NCAR Summer Colloquium, which was suspended several years ago because of budget pressures. The colloquium took the form of a course in atmospheric research instrumentation in summer 1983. Led and organized by Fred Brock of the Atmospheric Technology Division, the course was given principally for staff from our member universities. Several professors had told us that few of their staffs were able to teach a course on instrumentation, and that NCAR could help them develop this skill. Following the course, Brock wrote a classroom manual on instrumentation, which is now available.

The 1984 colloquium topic was mesoscale meteorology. This course, given in cooperation with NOAA, emphasized new knowledge in mesoscale meteorology research and helped prepare scientists for STORM. We are tentatively planning a colloquium on atmospheric chemistry for 1985 or 1986. Scheduling will be dictated by need, and some years may have no colloquium.

d. NCAR visitors to universities

The flow of NCAR scientists to university campuses is another highly useful educational activity. Fig. 21, compiled for FY 1982, shows more than 300 events that involved an NCAR staff member on a university campus; these events ranged from short computer courses and seminars to service on thesis committees and collaborative research. (Three seminars given in one visit were counted as three “events.”) Note that the number of visits to work on thesis committees greatly exceeded the number of graduate research assistants, cited earlier. Numbers of NCAR scientists participate in thesis committees apart from our Graduate Research Assistant Program, and I would like to see these healthy numbers grow still larger.
In addition, NCAR scientists sometimes spend as much as a term at a university through our Affiliate Professor Programs or through ad hoc arrangements. The NCAR visitor teaches one or more courses and participates generally in the intellectual life of the university. Four NCAR affiliate professors visited campuses in 1983, and courses were given, either in connection with this program or otherwise, by Akira Kasahara, Douglas Lilly, Michael Glantz, Fred Brock, and others.

5. Overall allocation of resources

At the end of each year we rigorously calculate where our resources have gone, with special attention to how they have been divided among NCAR projects, joint projects, and support of university activities. We define these categories as follows: 1) NCAR Research: research performed solely by NCAR scientific staff; includes financial support of visitors who remain on the NCAR staff after completing their appointments; 2) University Research: funding of visitors who return to their universities after completing their appointments; efforts directly in support of universities, such as use of NCAR's aviation, computing, and field observing facilities, and data reduction carried out by those facilities; the portions of non-NSF-funded programs that support university investigators, prorated according to the affiliations of the principal investigators; support of graduate students; 3) Joint Research: all activities in which there is joint participation by scientists from NCAR and other institutions. Field programs, joint modeling efforts, and efforts that lead to joint papers are examples of activities included. Visitors working within and paid by an NCAR project are also included. 4) Other: support of research at non-university institutions. The kinds of activities included are the same as listed under university research above.

Fig. 22 shows the results of our allocation analysis for FYs 1977–82. There is substantial continuity from year to year and the NCAR number has been virtually constant. Large field programs such as CCOPE in 1981 and JAWS in 1982 have enlarged the proportion of support to joint programs.

From my view, our interactions with the universities are close to where they should be. We are expanding our programs as we can, within the limits of finite budgets. Even with limited budgets we have worked hard to get new aircraft, more computing power, more visitors—and to keep a good balance of activities. I look forward to working with you to strengthen all the efforts of the university-based atmospheric research community.