Prefatory Note—Education and Manpower in the Atmospheric Sciences

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As a society dedicated to professional as well as to scientific ideals, the American Meteorological Society has long been concerned with problems of education and manpower in the atmospheric sciences. Not since the period following World War II have these problems assumed such importance as today. The question then was how to consolidate and develop the enormous gains made in meteorology during the war years. Wartime education had as its primary goal the rapid training of large numbers of practitioners. The challenge of the postwar era was to improve the quality of meteorological education so that the new scientific opportunities that had emerged could be fully exploited. Thus for nearly two decades the main emphasis in meteorological education was the production of ever increasing numbers of well trained scientists. In an expanding job market, the specialists created in this process had little problem in finding employment suited to their skills.

Today the picture has changed—not just in the atmospheric sciences but in the sciences as a whole. The national mood and national funding policies no longer permit unbridled expansion in the scientific sector. Science funding has levelled, and a shift to slower, more controlled growth has set in. This has happened at a time when the success of our past efforts in upgrading meteorological education and enlarging our ranks has produced an unprecedented supply of Ph.D.'s and other highly trained workers. The supply of manpower, if not already out of balance with the demand, is dangerously close to being so.

Along with the changed funding situation has come a shift of scientific priorities. Science for science's sake no longer has popular appeal; the prevailing view is that science must be aimed more directly at the fulfillment of human needs. As a consequence, problems which transcend the conventional disciplines have come to the fore. The present educational structure is not well suited to handling these interdisciplinary problems. With the altered growth pattern and the new priorities, it is apparent that the time has come for a reexamination of the manpower requirements and education structure in the atmospheric sciences.

At the 52nd Annual Meeting in New Orleans, the Society took a first step in this reexamination in scheduling a half day session on the subject: Education and Manpower in the Atmospheric Sciences. The papers

It is a great pleasure to be here in New Orleans to join in this Symposium on Education and Manpower of the American Meteorological Society. I accepted Walt Roberts' invitation to discuss the needs for atmospheric scientists with some misgivings. The prediction of the future needs for people trained in the atmospheric sciences is a difficult task. However, the subject of this symposium is central to the future of atmospheric science and service, and to our future ability to contribute to the solution of many of society's problems. For these reasons, I welcome this opportunity to be with you.

Reliable statistics about our education and training efforts and the employment of meteorologists are not easy to obtain. However, there are bits and pieces available from numerous sources. In particular, I have used statistics from our own National Oceanic and Atmospheric Administration; Ken Spengler has been kind enough to make available to me professional and education statistics for the past decade from the files of the American Meteorological Society; and I have also used data compiled by the National Science Foundation as part of its National Register of Scientific and Technical Personnel.

Our nation has no overall long-range national plan for training meteorologists. Our national program results from a collective of decisions made by many individuals and many institutions, and at various levels of government, each making an assessment of the future. The role of the federal government in this process is an important one in guiding these individual actions.

At the federal government level, we establish policies, pass laws, fund programs, and decide what kind of services need to be rendered on a national basis. Our acts have a profound influence on our educational and training activities, not by establishing rigid plans for turning out a specified number of people trained in cloud physics, or weather forecasting, but through a host of indirect impacts. A federal decision to increase the national effort in weather modification results in additional funds to do research and development. Such funding in the form of research contracts and grants finds its way to our educational institutions and provides the necessary financial support for students in these fields.

On the other side of the coin, our educational and training institutions are continuously alert for new national trends affecting the education of their students. For example, as environmental deterioration looms as a major national problem, academic institutions gradually shift emphasis in their education programs to encompass some of these problems even before national decisions are taken.

I think it is possible to draw a crude analogy between our education and training enterprise and other kinds of commercial enterprises, recognizing always that there are substantial differences. For example, we can regard the federal government, state and local governments, and industry as providing a major segment of the market for the products of our universities. The products of our education and training enterprise are our students. The problem, as in any commercial enterprise, is to insure a market for the products, or to produce what the market requires.

Let's look at some of the characteristics of this enterprise. What has been the nature of its growth? One measure would be the number of professional graduates produced. A good measure of this would be the number of professional members of the American Meteorological Society, recognizing that this does not include all of the people trained in atmospheric sciences, and also includes many members who do not regard themselves as meteorologists. During the decade of the 60s there was a growth in our society's professional membership of about 67%—from 3400 to about 5300. If we judge growth by the increase in the number of educational enterprises, it has been a good business. The number of universities giving professional degrees—bachelors, masters, or doctorates—has increased by about 50% during the decade, from about 38 at the beginning to about 58 at the end. Incidentally, much of this increase occurred in universities awarding masters' and doctors' degrees. This characteristic says something about the heavy research and development flavor of the market.

During the last half of the decade, between 1965 and 1970, there was an average rate of increase in the number

The Changing National Needs For Meteorologists

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presented on that occasion are reproduced on the following pages. That these papers were of more than ordinary interest was attested to by the long and spirited discussion which followed their presentation. It is thus fitting that they have been assembled here for the benefit of a wider audience. Also included is a sample of questions which indicate the nature of the concerns expressed by the audience. Unfortunately the taped transcription of the question and answer period is not available for publication at this time.

The Society is indebted to Walter Orr Roberts, Commissioner of Education and Manpower, to the organizers of the session, Richard E. Orville, Edward S. Epstein, Peter A. Gilman, and Glenn Stout, and to the speakers for the valuable service they rendered in focusing attention on this critical subject.
of doctorates of about 20% per year. During the last year of the decade, a total of 132 doctorates was awarded by our universities. This is remarkable because in 1970 the total number of doctorates in meteorology in the U.S. was only about 700. In 1970, therefore, one year’s output of doctorates from our universities was equal to 20% of the total number then existing in the field. If this rate continued we could expect a doubling of the population of doctorates in our field in five years.

Based upon NOAA’s queries to approximately 37 educational institutions with significant programs in meteorology, it appears that during the 1972–1973 academic season 35 educational institutions will be turning out a total of 700 graduates with professional degrees. Recognizing that our sampling did not include all institutions, I would estimate that our educational plant during the next academic year will actually turn out close to 800 graduates. During the next academic year our educational plant will turn out a number of professionals equal to 15% of the total of the existing professionals in the field.

What have meteorologists been doing during the past decade? The only nationwide assessment of the employment characteristics of meteorologists comes from the National Register of Scientific and Technical Personnel, which shows that there has been about a 70% increase in the total number of meteorologists available for employment during the decade, increasing from a level of 3829 in 1960 to a level of 6637 in 1970.

How has the market for the product of this enterprise grown over the past decade? The only nationwide assessment of the employment characteristics of meteorologists comes from the National Register of Scientific and Technical Personnel, which shows that there has been about a 70% increase in the total number of meteorologists available for employment during the decade, increasing from a level of 3829 in 1960 to a level of 6637 in 1970.

What have meteorologists been doing during the past decade? I will focus on only four categories in which the bulk of meteorologists engage: Research and Development; Forecasting and Reporting; Teaching; and Management/Administration. At the beginning of the decade, by far the largest activity among meteorologists was forecasting and reporting. Approximately 45% or about 1700 professional meteorologists indicated that this was their primary work activity. This contrasted with about 17% (635) in research and development, 21% (819) in management/administrative work, and about 5% (184) in teaching. By 1970, there had occurred a significant reorientation of the way in which meteorologists occupied themselves. While those involved in forecasting and reporting still were the largest single group, 33% (2193), there had been a significant decrease in their percentage of the work force. All others increased. Those involved in research and development had increased to 18% (1228), in teaching to 7% (467), and management/administration to 27% (1755). This latter figure suggests that our field is not immune to Parkinsonian laws.

Perhaps the most interesting statistics of the decade involved the rate of increase of activities in each of these fields as judged by the number of people involved. Research and development activities underwent a 92% increase. Teaching outdid them all. There was an increase of 125% in the number of people involved in teaching in meteorology, to a total of almost 500. Management/administration was undergoing a rather substantial increase of 110% to a total of close to 1800. The really surprising figure, and the one that I believe must give us pause for serious thought, is the fact that the increase in the number of people involved in forecasting and reporting was only about 45%, to a total of some 2200.

Numbers such as these would certainly seem to indicate that the growth segments of meteorology were other than in the services. The education enterprise geared itself to these parts of the market, as evidenced by the high percentage of masters degrees and doctorates awarded during the latter half of the decade.

This, however, is not quite the whole story. We need to know, also, which national program activities these meteorologists were engaged in. Again, the only real survey on which we can base our estimates is that in the National Register for Scientific and Technical Personnel. These deal only with the meteorologists supported by federal programs, but since these represent the bulk of meteorologists, I do not think we will be too far in error if we use some of these figures to make our analysis.

Consistent records on a small number of program areas supported by the federal government go back only to 1962, but provide interesting data. For example, meteorologists involved in natural resources, health, and education-related activities have undergone the largest increases during the past decade. To me this reflects the growing national interest in problems of air pollution, weather modification, and education and training. Meteorologists associated with natural resources have actually increased by 100%, and with health by a total of 90%. Several fields such as those related to defense and space show decreases of 17% and 20%, respectively. However, these data also show that there are certain traditional fields, like agricultural meteorology, which have seen a slow but systematic increase—24%.

About 62% of meteorologists are employed by the federal government, split evenly between the military and the civil sides. Surprisingly, 15% of all meteorologists are employed in educational institutions. Only 12% are employed by industry or business, or are self-employed. The health of meteorology is almost totally dependent on federal funding. In fiscal year 1972, the federal government will spend a total of approximately $600 million on meteorological services and research, and development. This will include the field of aeronomy. Of this amount, approximately $400 million will be spent for weather services. These funds will be spent by some 10 different agencies. The Department of Defense will be the largest spender—$254 million—followed by the Department of Commerce/NOAA, which will spend about $177 million. The National Aeronautics and Space Administration at $55 million, and the National Science Foundation at $46...
million are the next two largest agencies. These four agencies account for about 85% of the total atmospheric science and service budget of the federal government. In 1965 the federal government spent about $284 million to support meteorological activities. Between 1965 and 1972, federal support increased by about 115%, with about $150 million of this increase neutralized by inflation.

Using the numbers of professional meteorologists reporting to the National Register of Scientific and Technical Personnel as a base, we find that in 1965 it required an investment of approximately $48,000 per professional meteorologist to carry out the national meteorological effort. By 1971, it required an investment of $87,000 per professional meteorologist. The escalation of this per capita investment is due in large part to the increased costs of computers, satellites, and other instrumentation and facilities that meteorologists now need.

With this figure, we can estimate the growth of the market required to absorb any given output of our education and training institutions. If our past experience holds, each professional meteorologist added to the work force in the United States will require an investment of approximately $90,000 by the federal government.

How much of a net addition to the work force can we expect, given the present size and capacity of our educational enterprise? Of the total number of professional graduates, which I have estimated should reach 800 in 1972-73, about 180 will not be new entrants into the work force since they are students on educational leave or being sent by some governmental agency to a university for training. About 210 of those receiving degrees will remain in universities, continuing on for their graduate or further advanced degrees. The universities themselves will take a small number of these graduates, about 25. Therefore, only about 50% of the total expected output will represent a net addition to the work force. If we assume a conservative attrition rate of 4% for the federal government, then we can expect it will absorb about 160 of the remaining 400 graduates. If we can assume also that private industry, non-profit organizations, self-employed meteorologists, will suffer a similar rate of attrition, then they will require 40 additional professional meteorologists annually. I have checked these statistical estimates against our projected NOAA needs in a normal year, which are about 120. It would appear that our educational institutions are presently turning out approximately 200 professional meteorologists each year who can be employed only if the federal government or private industry undertakes new programs requiring additional meteorologists.

Let us project that our educational plant will turn out professional graduates at the 1972-73 rate. To absorb the total output, the meteorological "new program" market will have to grow annually by about 20 million dollars ($90,000/meteorologist). If there were to be a 5% increase in costs and using a base of $600 million as the rate of annual federal expenditure, this would require an annual increase of about $50 million dollars of federal funding for meteorological activities. Let's say my estimates are accurate to about 20%. We are talking about an annual increase in federal expenditures in the range of $40–60 million or about a 7–10% growth rate. In my view this is not unattainable, and is comparable to the growth rate of the last half of the last decade. This crude analysis suggests that our education and training enterprise is about where it should be in terms of size and in terms of the output of professional meteorologists. It is roughly in balance with an attainable market growth rate.

Our nation lacks a forum which permits major employers of meteorologists, those responsible for national program formulation, and representatives of the education and training enterprise, to confer on mutual problems. I propose that one of the actions we take as a result of this symposium be the establishment of an Annual National Conference on Education and Training, to provide such a forum.

We have established a unique mechanism in our field, the University Corporation for Atmospheric Research. Better than any other group, it can stimulate the collective interest of the universities. I would further propose that the University Corporation for Atmospheric Research, with assistance from our Society, sponsor such an annual conference. To it would be invited key federal policy officials as well as key representatives of the private sector, to appraise the outlook and to make themselves available for comment and questioning by the education community. In turn, this could well be a forum in which the employers can get an annual feel for the education and training outlook.

However, this would be only one of many topics which I believe such a conference could assist in attacking. Let's look at some others:

1. Graduate, undergraduate, and under-undergraduate education. Our needs for people with various levels of training are changing rapidly as technology and science create new ways of doing things meteorological. As in the past we will need a balanced output of graduates at the bachelors', masters', and doctors' levels. We have a growing need for meteorologists with a greater depth of education in fundamental sciences than they have had before. Undergraduate training to the bachelor's level will be needed to staff the highly difficult weather forecasting and other weather interpretive tasks at the full professional level. We will need masters and doctors for research, development, and senior assignments in our major forecast centers.

However, there is today a need for a new class of "para-meteorologists"—individuals with a lower level of
technical training in meteorology, but adequate to enable them to deal with the routine servicing of many user groups. The National Weather Service has established an in-house program training meteorological technicians for public and specialized weather service functions. As this kind of activity grows in importance, what will be the role of our present educational institutions or our two-year community colleges?

2. Continuing education. Yesterday Dr. Cressman pointed out his growing concern with what he called "continuing" education in our rapidly changing science. This is clearly a present deficiency of our system. In an evolving science such as ours, continuing education is vital. We need to join with the academic community to examine ways in which we can jointly address this problem. How will this be done?

3. Bridging the working world and the world of education. I have the privilege of participating in the work of the Visiting Committees at several universities. The students I see express a deep desire to understand how their education and training relate to the work for which they are preparing. One way to bring about this understanding is to build into the educational process a systematic program of realistic work experiences. While we do have summer student programs in the federal government, I believe that they can be used more effectively in conjunction with our universities. I believe we can take a page from some of the practices of our sister science—geology. In that science the idea of spending a summer in the field doing geological field work as a staff member of the Geological Survey is well accepted. Both students and teaching staff participate. I believe the time has come when we should look seriously into these forms of education for our field. How should we jointly plan such a program?

4. Responding to educational needs of the developing world. My experience with problems of international education and training and international needs for meteorologists stems from my service as a member of the Executive Committee of the World Meteorological Organization. The single most important concern of the developing nations is education and training. The availability of adequately trained talent in the developing world is desperately low. The World Meteorological Organization has fostered institutions for the training of all kinds of meteorologists, from technicians to those at the doctorate level. What role can our educational enterprise play in assisting in the education and training for the developing world?

In the United States we probably have the most diverse group of students from foreign nations of any country in the world. Last year NOAA was host to 62 students from 33 foreign nations. These students were here study-
It is a distinct pleasure to have this opportunity to express a few thoughts on the subject of undergraduate education in meteorology. I'd like to take advantage of the time allotted to discuss some topics that are of particular concern to me.

In my view there are four distinct aspects to undergraduate meteorological education. Two of these involve students who are concentrating in meteorology as part of their undergraduate curriculum. One is the student for whom the bachelor's degree is an immediate introduction to a professional career. He may later return to the university for graduate studies, but his training at the university is primarily intended to prepare him to function as a meteorologist. In addition there is the student who intends to continue on to graduate studies, either in meteorology or in some other field of science.

We also meet, in the universities, students who are not going to take more than one or two courses in atmospheric science. These students, for whom meteorology is an elective, also fall into two categories. The largest group of these are the liberal arts students to whom a course in meteorology is part of their very limited exposure to science and technology. With respect to these students we are playing a very significant role in introducing them to the various basic ideas not only of meteorology, but of science and technology in general. Although I do not want to underestimate the importance of the role we play in teaching meteorology to liberal arts students, I would like to emphasize the fourth group of undergraduate students who enroll in meteorology courses. These students are studying various technical fields such as science and engineering and, for one reason or another, also elect to study some meteorology. I have the very strong feeling that we have not really been paying as much attention to this group of students as we might.

Let us look first at the undergraduate meteorology majors. I remember arguments a few years ago as to whether or not it was appropriate to teach meteorology as an undergraduate degree program. From my point of view that question has no validity. In the first place there is a real job that can be done by students who have undergraduate training in meteorology. In the second place, we need make no excuses for the quality of students who, as undergraduates, have studied meteorology in most of our universities. In terms of their preparation in the basic sciences, in mathematics and physics, and in terms of their ability to continue on to graduate work, they compare very favorably with students emerging from any science or engineering curriculum. I see no difficulty in offering, within the context of a fully adequate education, the kind of geophysics and atmospheric sciences that constitute a very substantial major in meteorology.

I do not contend that every program must offer an undergraduate degree, and I certainly would not prescribe what such programs should look like. One of the strengths of our national program is the variety of training and approaches to meteorological problems that undergraduates see. The weather services and other employers of meteorologists benefit greatly from the variety of backgrounds of students who emerge from different institutions and then mix and mingle in their professional careers.

I would hope that students emerging from all of our programs have enough flexibility and adaptability that they may without penalty either stop their formal education, go on in meteorology, or move into some other discipline. Some of our programs may be more strongly oriented in one direction or another, but I sincerely hope that none of them restricts the student's program so much that he cannot change his plans freely. As educators our first responsibility must be to the student, and sometimes we may have to be adamant in order to insulate the adaptability of our programs in spite of specific desires of the student. For example, in the discussions of the last couple of days the broadcasters have strongly stated that training students specifically for such a narrowly defined objective as weathercasting would benefit neither the student nor the profession.

I had intended to avoid making any specific comments on undergraduate curricula—either what they are or what they should be. (One of the problems of defining what they are is that our catalogs are frequently inaccurate and out of date.) I would, however, like to make one brief comment on the subject of synoptic meteorology. Synoptic meteorology in undergraduate curricula has seen its downs and ups. In the 1960s there was a tendency to weaken synoptic input into the programs, but I think that tendency has been reversed. I hope this trend continues and that we put synoptic meteorology on a more solid footing in relationship to the other kinds of subject matter that we teach. It is hard for me to visualize an effective meteorologist at any level, undergraduate or graduate, who does not have some understanding and appreciation of weather, and to me this is what synoptic meteorology is about.

If there is anything about the undergraduate programs in general that concerns me, it is that we do not now give sufficient emphasis to areas where meteorology is applied. I do not mean this in the usual context of applied meteorology, in which one tries to emphasize a host of applications of meteorology. Certainly every
student cannot study in depth every area to which meteorology may be applied. But I do think that every student should be very aware of the economic and social impact of meteorology, and should have some working knowledge of one of these areas of application. Then, to top it off, we must put into our programs a great deal more emphasis on such areas as decision analysis and operations research so that students will be in a better position to see how their meteorological training can interact with the kinds of applications that do take place. Truly applied meteorology will require two sorts of specialists: well-trained meteorologists with an appreciation of the areas to which application is to be made, and a good knowledge of the methodology for applying this knowledge; and specialists in the area of application who also have a good understanding of how applications are made and an appreciation for meteorology. The important environmental problems of today are the kinds of problems that will be solved only with teams of specialists. But these teams of specialists must know how to work together. Meteorologists are essential members of these teams. To be effective members they must understand the nature of their interaction with other team members.

Let me now move away from the subject of meteorology majors and talk about our undergraduate teaching of those students who are not concentrating in meteorology. Teaching a nontechnical meteorology course to large numbers of undergraduate students is a very worthwhile undertaking. There is no doubt in my mind that we benefit as a profession from good public understanding of our role, and that the public, itself, is far better off with an appreciation of the role that meteorology plays in the world. This kind of teaching is done very effectively at many of our universities. I think this effort must be continued, and I do not want the emphasis of the remarks I am about to make to detract at all from the importance I place on the large nontechnical survey course.

I would like to see much greater emphasis on technical introductory courses in atmospheric science—technical survey courses, if you prefer. This may be a single semester course or it may cover two semesters. It is designed for students from various fields of science and engineering who already have a substantial background in mathematics, physics, and chemistry. Included in this group are the people who, working with us, will allow us to make real progress toward solving environmental problems.

When we talk of the great awareness today of environmental matters, I think we have to distinguish between two related groups. One group is conveniently referred to as the environmentalists. These people are very effectively making us aware of critical environmental problems that are either with us now or are imminent. They are identifying problems that cry out for solution, and in that sense they are playing a very essential role in our coming to grips with our environment. However, identifying these problems is not enough. For the most part these are technological problems, deeply integrated with our whole technological society, and they will require, in large part, technological solutions. One of our primary concerns must be that the scientists and engineers who are going to be asked to solve these environmental problems, so many of which are intimately related to the atmosphere, have an appreciation of the role that the atmosphere plays. They do not get this appreciation by studying chemical engineering or by studying physics. It is not enough, for example, that the civil engineer has had a course in air pollution in which he has learned that given some crude stability classification and some wind speed, you can go to a table which says something about the dilution of an effluent. The other day we heard about the problem of convincing those with regulatory responsibilities of the important difference between standards of emission and standards of air quality. This is symptomatic of a failure by many, who otherwise have good science and engineering backgrounds, to appreciate the role of the atmosphere and of the meteorologist. I do not think that we have made sufficient effort at the university level to expose the budding engineers and scientists to atmospheric science. They must appreciate what knowledge of the atmosphere can do for them and what the limitations of that knowledge are. We must develop the kinds of courses that build upon the technical training these people already have and make them much more effective colleagues in our mutual efforts to solve our environmental problems.

Let me try to make the distinction a little clearer. A chemical engineering professor told me that they were doing an effective job of teaching engineering concerned with environmental matters by teaching people how to design plants that would not put out any effluents at all. This may be a useful and difficult design problem, but I am sure that it's very expensive and so impractical that it will never be built. It seems to me that the role of an engineer should be to create a design that is optimal by some criteria. That optimization must involve the interaction of the subject of the design and the environment in which it operates. It is not necessary that there be no effluents. It is necessary that the subsequent behavior of the effluents and their impact, both locally at large, be considered and explicitly taken into account in the total design process. I want the engineer who is on the team dealing with the environmental problem to have an appreciation for meteorology, just as I want to see the meteorologist be aware of areas of application. Meteorology is so essential to environmental problems that I would like to see almost all people who deal with environmental problems from a technological point of view have some training in meteorology. This is an area in which both undergraduate and graduate institutions teaching meteorology can make a great deal more effort. If we do so I am confident that our offerings will be well received.
I hope you will excuse me for not relating my remarks more closely to those of Dr. White. In conclusion, however, I would add that I have unyielding confidence so long as we are able to deal effectively with the problems of the day, and so long as the education we provide prepares young men and women for those tasks, there will exist the opportunity and demand for our collective and individual services. I would argue vehemently against any retrenchment in meteorological education. As I interpret Dr. White's remarks there is no need for retrenchment, but neither is there any call for continued expansion. So it seems that now, more than ever, our efforts must be directed to doing our jobs the very best we know how.

**Graduate Education in Meteorology**

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Last June, Dick Orville, in behalf of the committee arranging this symposium, asked a number of university department chairmen to give their views on the problems to be discussed today. In preparing this talk, I have had access to excerpts from the replies of many of my colleagues. I have also had extensive discussion with faculty colleagues, both at Florida State University and elsewhere, about the problems we face.

But really these things do not dictate the material to be presented. There is no unanimity among academic meteorologists—frankly, there is confusion, frustration, and uncertainty. I can tell you something about our common problems, but in the final analysis the opinions expressed and the emphases given will have to be my own.

**Problems in graduate education.** To understand our problems, you should first reflect on some of the figures quoted by Dr. White covering the 1960s—a 92% increase in research and development personnel, a 50% increase in the number of universities giving meteorology degrees, a 20% per year increase in doctorates during the last 5 years. To these one might add the doubling or tripling of faculty salaries and the tremendous expansion of federal support during this period.

The decade of the 1960s was a golden era for all science, perhaps more so than average for atmospheric science and for graduate education in atmospheric science. Today, we face a completely different situation. The big bulge of war babies has passed through the universities, the public has become disenchanted with research and graduate education as new national problems achieve higher priority, the challenge of Sputnik (which had much to do with the events of the 1960s) has been answered or perhaps forgotten, campus unrest has undermined public confidence, the supply of Ph.D.'s was scarce and there was some question about expansion of graduate education. As another example, in September and October of 1957 we at the Geophysics Research Directorate of the Air Force Cambridge Research Center (which was then the principal funder of university research in meteorology) were telephoning university scientists and actually cancelling contracts. We recovered from those troubled times, and the present situation will undoubtedly improve in the years ahead. However, in perspective, perhaps the 1960 decade was an anomalous period, not a normal one. The pendulum will swing back but probably not into another period of expansion comparable to that of the 1960s.

As another bit of perspective, please be reminded of the low state of repute of meteorology as a science, say, 20 years ago. True, there were some excellent scientists in meteorology, but not very many of them. Many of us in my generation and in the generation following us have been determined to prove that we could establish top notch Ph.D. programs and that atmospheric science is really a science. In large part, we have accomplished this; we have no reason to question the general quality and standards of our graduate education and our research. We must not give up this accomplishment, we must never sacrifice our standards in the name of relevancy or of growth simply for the sake of growth.

You all know these things. But in behalf of those of us actually engaged in graduate education, let me point out to our colleagues in government and industry some of the specific effects on our day-to-day operations. The problems of state universities are better known to me, but there are corresponding difficulties in the private universities. State legislatures are doing several things—they are passing classroom teaching laws, they are limiting graduate enrollments, they are decreasing research "positions," they are asking about the "market" for graduates in various programs and trying to put their money where they think the jobs are, they are demanding "relevancy." To say that some of these things are short-sighted is to beg the issue, because they are happening. We are going through hard times in the universities, especially with regard to graduate education and research, in stark contrast to the situation only 2–3 years ago.

Some perspective. It seems desirable to try to provide some perspective, based on nearly 30 years of varied experience in meteorology. Life has not been universally rosy during that period. For example, during the late 1940s, when we were winding down the World War II effort and before the Korean affair and the Soviet development of atomic and nuclear weapons, jobs for Ph.D.'s were scarce and there was some question about expansion of graduate education. As another example, in September and October of 1957 we at the Geophysics Research Directorate of the Air Force Cambridge Research Center (which was then the principal funder of university research in meteorology) were telephoning university scientists and actually cancelling contracts. We recovered from those troubled times, and the present situation will undoubtedly improve in the years ahead.

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But really these things do not dictate the material to be presented. There is no unanimity among academic meteorologists—frankly, there is confusion, frustration, and uncertainty. I can tell you something about our common problems, but in the final analysis the opinions expressed and the emphases given will have to be my own.

Problems in graduate education. To understand our problems, you should first reflect on some of the figures quoted by Dr. White covering the 1960s—a 92% increase in research and development personnel, a 50% increase in the number of universities giving meteorology degrees, a 20% per year increase in doctorates during the last 5 years. To these one might add the doubling or tripling of faculty salaries and the tremendous expansion of federal support during this period.

The decade of the 1960s was a golden era for all science, perhaps more so than average for atmospheric science and for graduate education in atmospheric science. Today, we face a completely different situation. The big bulge of war babies has passed through the universities, the public has become disenchanted with research and graduate education as new national problems achieve higher priority, the challenge of Sputnik (which had much to do with the events of the 1960s) has been answered or perhaps forgotten, campus unrest has undermined public confidence, the supply of Ph.D.'s was scarce and there was some question about expansion of graduate education. As another example, in September and October of 1957 we at the Geophysics Research Directorate of the Air Force Cambridge Research Center (which was then the principal funder of university research in meteorology) were telephoning university scientists and actually cancelling contracts. We recovered from those troubled times, and the present situation will undoubtedly improve in the years ahead. However, in perspective, perhaps the 1960 decade was an anomalous period, not a normal one. The pendulum will swing back but probably not into another period of expansion comparable to that of the 1960s.

As another bit of perspective, please be reminded of the low state of repute of meteorology as a science, say, 20 years ago. True, there were some excellent scientists in meteorology, but not very many of them. Many of us in my generation and in the generation following us have been determined to prove that we could establish top notch Ph.D. programs and that atmospheric science is really a science. In large part, we have accomplished this; we have no reason to question the general quality and standards of our graduate education and our research. We must not give up this accomplishment, we must never sacrifice our standards in the name of relevancy or of growth simply for the sake of growth. But perhaps the time has come to stop being paranoid about it, and to admit that there are additional worth-
while objectives in our university programs, graduate and undergraduate, other than producing more university professors and pure research scientists. At the graduate level, we already have and can further develop terminal M.S. programs and other alternatives.

**Questions for the future.** We find ourselves today with no room for expansion in terms of the traditional job opportunities for our graduates. Let me ask a series of questions for the future to which we should as a group address ourselves.

Why should there not some day be in every junior college in the United States a teacher with a major or minor in meteorology at the M.S. level? The non-scientist is hungry for information about the atmospheric environment, if properly presented.

Why should there not be in many major universities which do not have meteorology degree programs a teacher, perhaps attached to the physics department, with a major or minor in meteorology at the Ph.D. level—not primarily to produce more Ph.D.'s, but to teach basic and more advanced courses in meteorology? Why have we largely abdicated this responsibility to non-meteorologists?

Why should there not be a B.S. or M.S. meteorologist in every city and state pollution control agency?

Why should not major industries want meteorologists on their staffs, to serve much the same purpose as staff officers in military organizations? The weather affects their operations to an increasing degree.

Why should not the education of WMO and other sponsored students from undeveloped countries be a bit more aimed at the problems of those countries—agriculture, administration, observing, forecasting?

Can we sell the need for meteorological services to new customers, so that 62% of meteorologists will not have to be employed by the federal government? Can we, as a group, adjust to changes in our educational objectives?

The message from all projections, all predictions, is that the number of traditional Ph.D.'s to be educated in the next decade cannot continue to increase at its present rate. While answering the above and similar questions and searching for growth in a diversification of educational objectives, we must, however, not sacrifice the quality of Ph.D. education. We must continue the trend of emphasizing the fundamentals of mathematics, physics, and chemistry for those who will tackle the basic problems of understanding atmospheric processes. Good research is always relevant, although the time and type of application may be uncertain.

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**Comments on Education in the Atmospheric Sciences**

Harry Hamilton

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I have the somewhat dubious honor of being your token minority group representative here. Now that society is trying to change at least some of its practices and procedures along racial lines from what it has been over the past few hundred years, I assume someone in the audience is going to want to talk about how this relates to meteorology. I don't, but I'm sure you do, so I'll be available for questions and comments later.

I would like to spend my time talking about one aspect of meteorological education—that is my concern about the education of non-science majors and non-scientists being trained in meteorology or at least exposed to it. I think it is very important because it is obvious there will be more of them than us—more non-scientists than scientists, particularly more than meteorologists. These people are going to be the ones who will be making the bulk of decisions that affect us, both as to the research we do and to the application of any of the results. For this reason, I think it is very wise for us to have an enlightened decision-making body. Particularly when we get into the area of weather modification, we are talking about and working with perhaps the potentially greatest benefit or detriment to mankind, even greater than the nuclear energy we have had around for 25 years or so. Unless we understand and understand the decision-making group understands to a fair degree the potential we are now dealing with—the total effect, side effects, and some of the options—I fear we will be in even greater trouble than we are with the control of nuclear weapons.

I think we need to give as many people as possible an understanding of the atmosphere: the forces involved in the atmosphere, their interaction, and the possibilities and potentials for changing or modifying them. We need to emphasize the global nature of the atmosphere and its motions, which, as we all know, recognize none of the distinctions that man loves to make as far as territory or people are concerned. I think it is important, and it was mentioned in other talks this morning, that we have been doing a reasonable job to educate the non-science people, particularly the non-technical non-scientists, but I want to speak strongly for our continuing to do as much of this as possible because I feel it is very important for society in general and it is self-serving for ourselves.

I would like to make one other comment that relates to one of the remarks made by Dr. White. I think it is very important that we plan for orderly growth or even stabilization of the field of meteorology. If anyone knows that this earth is finite, it should be meteorolo-
gists, since we are dealing with the same atmosphere over and over again. We cannot continue to grow forever. We have grown rapidly in the past decade, as Dr. White mentioned. A continuation of that 7% growth just can’t go on. We should begin to think of a steady-state situation where there is no growth. For if there is growth in meteorology, something else is not growing. We must set priorities in order to sustain a reasonable expansion. We must arrive at an answer to the question: If we are now more important than some other field or some other endeavor, how much longer are we going to be more important? I think that we cannot be blind to the fact that while the pie might be increasing slightly in size, it is a pie that has to be divided, and if we take a larger share someone else is going to get a smaller share. I think we should adjust ourselves to this as we plan for our future, both in the sense of education and job opportunities.

Undergraduate Training in Meteorology

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I would like to discuss my concept of undergraduate education in meteorology and why I think it is necessary. These ideas grew over the last several years at Penn State where I’ve come into contact with fellow students who have had no, little, or extensive training in meteorology at the undergraduate level. Even those with B.S. degrees in meteorology had very dissimilar undergraduate experiences. Through dialogue and my own observations these people have revealed to me the strengths and inadequacies of their preparation and the problems they have encountered as a result.

First, meteorology should be taught on the undergraduate level, both to terminal students and future graduate students. However, these two groups of students have very different needs. As I detail these needs I hope to point out why meteorology is one of them and how much meteorology is necessary.

Terminal students should not be required to pursue "pure" physics beyond a general science requirement, math beyond several variable calculus, or advanced chemistry or computer science. Sophisticated concepts of math and physics should be taught within the context of meteorology courses if needed. This is similar to the approach used in many engineering programs.

Meteorology should be the emphasis beyond the sophomore year. Synoptics and dynamics are musts. Electives should be selected from two groups, other specialized areas of meteorological science (climatology, cloud physics, etc.) and applied meteorology (forecasting, instruments, environmental meteorology, public and industrial applications).

The idea is to produce people who a) are in tune with the atmosphere in a scientific and intuitive sense and b) can use their understanding and practical knowledge to produce useful products or sound advice. We should train our meteorological engineers and forecasters as meteorologists, not physicists.

Students who aspire to graduate school should be required to pursue a certain minimum amount of advanced and applied math, thermodynamics, and fluid dynamics beyond general physics, and possibly advanced chemistry or computer science. They need a more fundamental grasp of physical principles and mathematical techniques; graduate school is too late to start obtaining this.

A minimum of meteorology nonetheless is still essential (general meteorology, six credits of dynamics, six of synoptics, six of electives). These students should have the opportunity, on the undergraduate level, to see physics at work in the atmosphere, to consider the classical approaches and applications of science in meteorology, and learn the everyday jargon and tools of meteorologists. I’d like to quote Prof. George Freier who replied to a memorandum soliciting comments on Education and Manpower Needs in meteorology. He had recently initiated a course in cloud physics for physicists and he made this remark:

The cloud physics was aimed at making physics relevant rather than making more cloud physicists. In the course I take elementary physical concepts from all areas of physics and develop them for applications in cloud physics. The students are much more interested in studying the acceleration of a column of air than they are studying the acceleration of a grindstone with a string wrapped around the axle.

This man used meteorology to make physics more relevant to physicists. Is it not logical then to use meteorology to make physics more relevant to meteorologists?

Also, early training in meteorology may be important in helping the student isolate specific fields of interest at the start of graduate school, and in building a basis of communication and understanding for later roles in the meteorological community.

Neither program should overspecify a student’s program. In other words, additional meteorology electives should be available for the future graduate students, math and science electives for the terminal students, or 6–12 credits of electives in some approved interdisciplinary field for both.

I would like to underline the fact that the principal difference between the two programs is emphasis in elec-
tive courses, not in basic meteorological education. Through careful planning of course content and requirements and sound advising, meteorology departments can eliminate both the necessity for a student choosing an option before his senior year and teaching two meteorology sequences. Both programs are compatible and any strong meteorology department could accommodate them.

To summarize, I believe a sound undergraduate meteorology program is important to anyone who plans a career in meteorology. With options available and careful advising a student can optimize his preparation for the next stage in this career. Training in meteorology must not be sacrificed in the name of "interdiscipline" or "relevance." Our students must be convinced, as I am, that a knowledge of the atmosphere should be their primary goal—satellite interests should be developed, but not at the expense of meteorology.

**Broadening the Outlook of Meteorology**

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My concerns have much in common with those already expressed by previous speakers. Representation of meteorology in our society appears to be far less than it might be due partly to the fact that meteorologists do not enter certain areas where their knowledge could be very useful.

We all know, of course, about the specialized forecasting done by private agencies and about agricultural applications of meteorology, but there are other areas in which meteorologists could contribute. One such area might be called meteorological design and engineering. If a road is to be put in, more needs to be considered than contours and drainage. Snowfall might vary significantly over a fairly small area and should be considered. In the area of building design, engineers apparently consult a book for climatological data for the city where the building is to be constructed. The data consist of one set of numbers for the entire city and its environs. It seems reasonable that knowledge of the microclimate where the building is to be located would enable optimal design of the building. On a larger scale, consider the Aswan Dam miscalculations. Where were the meteorologists when it was being planned?

There are numerous examples of the needs. The University of Wisconsin has many buildings. At one location it was discovered that one building's exhaust was being drawn into the intake of the same building. Certainly engineers can handle many aspects of design, but where buildings are located close together, can engineers anticipate all of the complex interactions of the atmosphere?

There have been some restraints on developing broader involvement of meteorology. A major restraint is the great dependence upon federal government support. As indicated earlier by Dr. Robert White, 62% of all professional meteorologists currently are employed by the federal government. Many more receive partial support from federal funds. This situation has not given the profession incentive to seek out actively other ways to contribute meaningfully to our society. A look in the Madison phone book shows over 40 engineering consulting firms listed. I venture to say that there is no meteorologist employed in any of them.

Another restraint is our stress on full graduate programs leading to M.S. and Ph.D. degrees. In the book, *Career Opportunities: Ecology, Conservation & Environmental Control*, published recently by the J. G. Ferguson Publishing Co., the word meteorology appears infrequently. Why are we represented so sparsely in this book of general information for students desiring a two-year, post-high school education for a career in environmental work? Odom Fanning in his book *Opportunities in Environmental Careers* claimed that the number of new job positions for meteorologists will increase by 8000 between 1970 and 1980. He compared that with an American Meteorological Society estimate of one to two hundred in the next few years. This comparison emphasizes the discrepancy between how we see our role in society and how others see it. We need to expand our horizons.

To return to the education issue itself, the limiting factors in the current system are evident. The expanded role for meteorologists which I am proposing will require far more interaction with engineering, business, and medical sciences. At the University of Wisconsin these are each in a different college or school. Undergraduate meteorology majors are in yet another unit, the College of Letters and Science. Furthermore, for graduation, nearly all their courses must be taken in the College of Letters and Science. This precludes the diversity which I believe meteorologists need. In my opinion the M.S. degree should be more viable as a terminal degree, not merely a recruiting ground for Ph.D. students. And in connection with this I also believe that the ratio of Ph.D. to M.S. degrees should be decreasing rather than increasing as is currently the situation. This goal could be achieved not necessarily by reducing the number of Ph.D.'s, but by developing a more useful masters program which can open doors for more employment possibilities.
I appreciate this opportunity to participate in the Education and Manpower Session of the American Meteorological Society. During this brief presentation I will try to convey the students' viewpoint on some of the important questions facing meteorological education today. There will be some repetition of the remarks made by other speakers but it is informative to know that students and faculty members can hold the same opinion on some issues.

I agree with Bob Livezey that many meteorological undergraduates are unhappy with present curricula. As pointed out before, there seems to be the desire to have two different undergraduate curricula: one for the terminal B.S. student and one for those who wish to pursue graduate work. One difficulty with such a program is that most students do not know by the end of their sophomore or junior year whether they are going to attend graduate school. Thus, by choosing one of the two options so early in his academic career, a student may be doing himself and the meteorological profession a disservice. Also, most meteorology departments are not capable of supporting two different undergraduate programs. One solution to this problem could be to have all undergraduates go through the same program at least through the junior year. During the senior year, if a student feels that he might continue his studies, he would take additional courses in mathematics, physics, and statistics, along with the advanced undergraduate courses in dynamic and physical meteorology. A terminal B.S. student should still acquire a background in basic statistics and computer programming while taking more courses in synoptic meteorology, applied meteorology and climatology, pollution studies or other areas which are related to the atmospheric sciences.

Another problem concerning curriculum is the students' constant demand to make it more "relevant" to today's problems. It is very important for meteorology departments to respond to changing atmospheric and environmental problems. Otherwise, our graduates will not be competitive in tomorrow's job market. On the other hand, it is impossible for most meteorology departments to teach all the applied type courses that students might want. The reason for this is more than logistic: there seems to be a lack of applied meteorologists at the universities. Thus, as has been said before, inter-departmental and even inter-university programs must be developed so that students may take courses in subjects like biology, chemistry, oceanography, and engineering that will prove useful to them in some aspects of applied meteorology. Somehow these courses must be designed so that they are advanced enough to be beneficial, but do not require the student to wade through many terms of prerequisite courses.

We should note that while our atmospheric science departments are asking for cooperation from math, physics, chemistry, and statistics departments to make some of their courses more useful to the meteorology major, all of our departments should see if they are providing beneficial courses for interested biology, chemistry, engineering, and physics majors. Some people may oppose this idea, one reason being that our profession is especially susceptible to the "a little knowledge is a dangerous thing" problem. For example, one reason that we have the pollution crisis today may be that industry tends to hire engineers with little knowledge of meteorology rather than meteorologists with little engineering background to solve its pollution problems. Again, the only solution to this problem is to develop interdisciplinary degree programs with engineering, chemistry, or environmental studies departments. Students in these programs should most likely terminate at the M.S. level.

Although demands for relevance and more interdisciplinary cooperation should be met to some degree, atmospheric science departments must not turn away from stressing a strong math and physics background along with courses in the basic areas of dynamic, physical, and synoptic meteorology. In fact, even most students agree that all Ph.D. candidates should still have their education based on these fundamental disciplines. Then upon receiving their degree, they will be prepared to apply themselves to whatever problems become relevant in the near and distant future. Training Ph.D.'s for the fads of today may prove to be a mistake.

I also want to emphasize the importance of extending our influence into the secondary schools. Conventional physics courses in high school could be made much more interesting to the student and beneficial to our profession if the curriculum were oriented around geophysics. That is, the earth-atmosphere system could be presented as a stage on which the laws of physics are constantly demonstrated, as well as the applications and limitations of these laws. Thus, at least one geophysical science major ought to be included on all high school faculties. This would help enlarge the job market for our B.S. and M.S. graduates as well as helping to steer interested, bright students into the geophysical sciences.

Another problem that concerns most students and is not restricted to the field of atmospheric sciences is that of the instruction. Many professors, most of whom would make good teachers, just don’t have enough time to prepare good lectures or design new and better courses. This is due partly to the increasing load of administrative duties they perform and to the "publish
or perish" practice of many universities. Professors who just teach don't seem to advance very far. Atmospheric science departments should recognize and support good teachers, especially since the increasing interdisciplinary nature of our profession should make extensive instructor preparation a must. Thus, a professor, if he wishes, ought to be able to devote himself to the educational progress of our students without penalty. Students agree wholeheartedly that how much and how well they learn is much more a function of the teaching ability of the instructor than the research accomplishments of that instructor. Of course, by the time a student reaches the Ph.D. level, this last statement is no longer true.

Many other comments could be made about the problems concerning today's students but time does not permit elaboration here. Obviously, financial difficulties are a continuing problem. The fact that state legislators are not as favorable to graduate education as they have been is a problem that we all should be concerned with. I hope that progress will be made on the problems we have mentioned today and that the student viewpoint will continue to be solicited in the future.

A Sampling of Questions

The nature of the concerns expressed by the audience is indicated by the following sampling of questions.

We have seen how the number of persons involved in meteorology has increased, and certainly how costs of training and utilizing them have increased over the past six to ten years. Since the need for scientists also must be based upon demands (e.g., service) from our customers, how much has the "value received" from the atmospheric science function increased over a like time-period? If there is no quantitative answer, what steps are being taken to gather data to enable the question to be answered?

Where are the 12,000 meteorologists trained since 1940? Half are in peripheral or even unrelated fields, and probably do not regret the cultural background of meteorology. Thus, why should we worry about the full absorption of graduates?

Are you able to distinguish, in the indicated growth rates for production of meteorologists, between a) the real programmatic growth; b) the apparent growth that results from a broader definition of "meteorologist?"

If, as alleged, the educational system is overproducing at the baccalaureate level, why does the Air Force have to financially sponsor meteorologists through ten civilian universities?

In the 1950s several distinguished committees forecast a critical shortage of meteorologists. No crisis, in fact, developed. Why and what does this imply now?

Who should initiate and formulate the new programs needed to absorb the estimated 200 excess meteorologists being trained, and how should this effort be carried out and funded?

I suspect that there has been a genuine overproduction of Ph.D.'s in geophysical hydrodynamics from meteorology and oceanographic departments. How should we try to limit these kinds of overproduction?

The Director of the Air Pollution Control Commission of a major city recently told me that he did not plan to add a meteorologist to his staff, because: 1) his budget is thin; 2) he wouldn't know how to supervise or even communicate with a meteorologist; 3) NOAA provides enough information to satisfy his needs anyway. What can we do to "sell meteorology" to such officials, who in this and many other application areas are almost invariably non-meteorologists?

Is meteorology as applied to air pollution and other environmental problems a five- or ten-year "fad," or will it continue over the long term at a sustained high level of support?

In addition to some work-study programs, what contributions can the national laboratories of NOAA, NASA, and NCAR contribute to education?

You have stated that the universities are producing about the right total number of advanced degree holders in meteorology. Within that number, do you see the need for any shifts in emphasis in types of Ph.D.'s produced? For example, more cloud physicists and fewer dynamicists? More air chemists?

Would it be possible to pursue an interdisciplinary graduate degree for a forecaster who wishes to remain a forecaster, i.e., meteorology/sociology or meteorology/journalism?

What are the pros and cons of thesis and non-thesis M.S. degrees?

How should the universities react to the demands for relevance and for people to staff new specialties: by more specialization in education or by less?