Are We Graduating Too Many Atmospheric Scientists?

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1. Introduction

During the past few years, a number of articles in both scientific journals and the popular press have suggested that scientific disciplines ranging from physics to biotechnology are now faced with an excessive number of scientists. For example, the Washington Post (25 December 1994) notes that while the number of scientists has increased steadily over the past several decades, federal funding of scientific research has been flat (in constant dollars) since 1987. David Goodstein, vice provost at the California Institute of Technology, suggests that we have entered a "permanent era of constraint" in which the continuous and rapid growth of American science has ended (Seattle Times, 9 June 1994). He notes that underlying employment problems are being partially mitigated by postdoctoral "holding tank" appointments and that American students are being replaced by foreign nationals in many university programs. Employment problems in physics have received particular attention; advertised positions have been flooded with applicants, and many graduates are bidding their time in a series of postdoctoral appointments (Ellis 1993). White (1991) suggests that too many scientists are chasing after too few dollars, resulting in adverse effects on the productivity of science and engineering research. Massy and Goldman (1995), simulating the supply and demand of science and engineering doctorates, conclude that about 22% of the new doctorates fail to find suitable employment. A recent study of the National Academy of Sciences (1995) predicts that the current period "is likely to be vastly more consequential for the employment of scientists and engineers than any previous period of transition."

Some observers of this scene ask whether American science should be reorganized for a period of steady-state or even falling support. Clearly, funding for science and other discretionary items in the federal budget will be increasingly constrained by the rising costs of entitlements and interest on the national debt, coupled with attempts to limit the size of the federal deficit. As this article was undergoing final revision (November 1995), the U.S. Congress was considering substantial cuts in science/technology research and development, and federal agencies such as the National Weather Service and the U.S. Geological Survey were reducing their scientific staff.

Ironically, only a few years ago several reports suggested a shortage of scientists (e.g., Atkinson 1990; Vaughn and Rosenzweig 1990); as noted in Gibbons (1994), such concerns were disseminated by prominent figures in the scientific community who warned that the country needed to train more researchers. Some funding agencies responded with enhanced graduate student and postdoctoral support, encouraging increased production of scientists at a time when employment opportunities in many fields were actually stagnating.

Although the atmospheric sciences have fared better than many other scientific disciplines, there is some reason for concern regarding future employment prospects in the field. At the doctoral level, the decreased availability of academic positions, the tendency for some Ph.D.s to be "parked" in postdoctoral appointments, and increasing difficulty in acquiring funding have become evident. Concerns regarding employment have extended to master's and bachelor's degree recipients as the period of rapid growth in the National Weather Service reaches its conclusion and the military services reduce their hiring of new weather of-
Private sector employment is growing, but it is uncertain to what degree such growth will mitigate decreased opportunities in other areas.

This article considers issues of employment and education in the atmospheric sciences, with particular emphasis on the graduate level. A review of the growth of the discipline from the Second World War to the present is provided, recent trends in employment and funding are reviewed, and recommendations are made on steps that might soften the transition to a new funding and employment regime.

2. Historical trends in demographics, funding, and graduations

To understand the current employment situation in the atmospheric sciences and possible future trends, it is useful to consider historical trends in employment, graduation rates, and funding since the Second World War. During that conflict and in the decade that followed, the number of meteorologists increased rapidly. Many individuals were trained in meteorology for the war effort itself, and a number of them received formal degrees in the atmospheric sciences during the late 1940s and early 1950s. One measure of this growth is the noncorporate membership of the American Meteorological Society (AMS), which grew rapidly from approximately 1000 immediately prior to the war to nearly 7000 by the late 1950s (K. Seitter 1995, personal communication).

Support for scientific research increased rapidly in the post-Sputnik era of the late 1950s and 1960s; as noted by Fleagle (1994), U.S. federal expenditures for research and development grew from approximately $1 to $17 billion between 1950 and 1967. Support of atmospheric sciences research paralleled this trend, with the most rapid increase (from $37 to $222 million) between 1960 and 1964 (NRC 1971). Federal support for graduate education and university research in the atmospheric sciences increased from less than $3 million in 1958 to approximately $42 million in 1967, after which the rate of increase abruptly lessened (NRC 1977). As a result of this enhanced funding, there was substantial growth in the number of atmospheric sciences and meteorology departments during the 1960s (Orville 1978). Figure 1, reproduced from Orville (1978), shows that the number of atmospheric sciences departments and the quantity of bachelor’s, master’s, and doctoral degrees awarded by them increased significantly during the 1960s. For example, the number of institutions awarding bachelor’s degrees increased from the midteens to near 30, while the number of bachelor’s degrees awarded per year climbed from just under 200 to approximately 340. The most dramatic growth was in the number of doctoral degrees awarded per annum, which went from 39 in 1963–64 to 139 during the 1971–72 academic year.

During the second half of the 1960s, support of meteorological research leveled off (NRC 1971), and the number of openings in the NWS and in several research groups in NOAA declined. As a result, concern grew that “the supply of manpower, if not already out of balance with the demand, is dangerously close to being so” (Reed et al. 1972). With tightening fund-

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1 Of course, not all meteorologists were members of the AMS.
ing and the number of academic departments remaining nearly steady, graduations in atmospheric sciences at all educational levels plateaued during the early to the middle 1970s (Fig. 1). Fortunately, during this period there were additional positions for meteorologists in municipal and state governments, as well as in the private sector, because of increased environmental monitoring and pollution mitigation mandated by federal legislation such as the Clean Air Act of 1970 (Horn et al. 1974). Growing programs in weather modification and the expansion of the National Center for Atmospheric Research (NCAR) also helped maintain a balance between graduations and employment opportunities during the 1970s. Bretherton (1977), after analyzing graduation and employment statistics, noted that in the mid-1970s “there may now be a rough balance between the total flow of new doctorates into meteorology and the needs of the field.” Kellogg (1977), in a study of the membership of the AMS in 1975, found a bimodal age distribution, with peaks at 30–34 years (those entering the profession during the period of rapid growth of the 1960s) and 55–59 (the World War II–era meteorologists).

During the late 1970s and early 1980s, support for atmospheric sciences research and graduate education stayed roughly even with inflation, and the number of graduate students entering the job market each year remained approximately constant (AMS Board of Meteorological Education in Universities 1983). Figure 2, which shows the trends in graduations from a sample of 12 relatively active atmospheric sciences departments (Table 1), supports the contention of nearly steady state graduate student output during the period. Some variability in undergraduate enrollment is apparent, with an increase from the mid- to late 1970s, followed by a decrease during the 1980s.

Between 1983 and 1986, support of atmospheric sciences research increased considerably, primarily as a result of a rapidly rising NASA budget and modest increases at the National Science Foundation (NSF) and NOAA (Fig. 3); after the peak in 1987, total atmospheric research support declined. Graduate student and postdoctoral support in the atmospheric sciences division of NSF increased substantially between 1989 and 1992 (Fig. 4). As a result of concerns about a lack of trained scientists in the areas of climate and global change, a number of graduate fellowships and postdoctoral positions in this subject area were established during the late 1980s by NASA, NOAA, and the Department of Energy. As seen in Fig. 2, there were large increases in undergraduate and master’s graduation rates in the early 1990s and little growth

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2 These departments were selected because they were relatively stable and graduated large numbers of students. Data for this table came from Curricula in the Atmospheric, Oceanic, Hydrologic, and Related Sciences, published by AMS and UCAR.

3 A reviewer suggested that these changes in undergraduate enrollment might be explained by the aggressive programs of both the air force and navy to train meteorologists during the 1970s and the subsequent phasing out of such efforts during the 1980s.
in the number of Ph.D. degrees awarded. One might hypothesize that the increase in NSF graduate student funding and efforts by several agencies to support additional students in climate research contributed to the rapid rise in master’s degrees awarded during this period; since Ph.D.s typically require 5–7 years, the effects of increased funding on the doctoral level were not yet evident in 1992. One might also speculate that the large increase in the number of meteorologist positions at the NWS would have encouraged student enrollment at the bachelor’s and master’s level during this period.

During the 1980s, many of the WWII cohort retired, opening up positions in most sectors of the profession. This demographic trend is apparent in the age distributions found in the 1989 and 1993 surveys of the AMS membership presented by Stephens and Kazarosian (1992) and Zevin and Seitter (1994), respectively. Reproduced in Fig. 5, the 1993 distribution shows a broad age maximum between 30 and 45 and only a weak suggestion of a minor mode near age 70. Clearly, one should not expect a major surge of retirements during the next decade. While Stephens and Kazarosian found that most subgroups of AMS had similar age distributions, broadcast meteorologists were skewed to younger ages, with the mean in the late 20s and 30s. At least two effects might have contributed to this skewed distribution: first, there was a rapid growth in the number of broadcast meteorologists during the 1980s as television stations added news programs during the mornings and weekends. Second, the broadcast medium tends to favor a youthful look in its on-air personalities.

Figure 6 shows student graduation statistics for 1991–93, based on the 1994 volume of Curricula in the Atmospheric, Oceanic, Hydrologic, and Related Sciences. In creating this figure, the author only selected U.S. departments that offered a clear-cut atmospheric sciences curriculum (e.g., no oceanography departments). During this two-year period, there were 901, 477, and 205 degrees awarded at the bachelor’s, master’s, and doctoral levels, respectively. The number of institutions granting bachelor’s and master’s degrees in atmospheric sciences was approximately 60, and 45 awarded doctoral degrees. Figure 6 also displays the frequency distributions for graduations at each level. For bachelor’s degrees (Fig. 6a), most institutions graduated 1–15 students over the two-year period; however, several graduated over 30, with one

<table>
<thead>
<tr>
<th>TABLE 1. Schools used to evaluate student graduation trends.</th>
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<tbody>
<tr>
<td>Colorado State University</td>
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<td>The Florida State University</td>
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<tr>
<td>Lyndon State College</td>
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<tr>
<td>The Pennsylvania State University</td>
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<tr>
<td>State University of New York at Albany</td>
</tr>
<tr>
<td>Texas A&amp;M University</td>
</tr>
</tbody>
</table>

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institutions awarding 95! At the master’s level, the majority of the departments graduated less than eight students, although a few produced over two dozen (Fig. 6b). Far fewer students finished at the doctoral level, with most departments graduating less than five over the two-year period (Fig. 6c).

A comparison of the 1991–93 graduation statistics shown in Fig. 6 with similar information from Orville (1978) for the 1960s and 1970s, suggests that graduation rates at the bachelor’s, master’s, and doctoral levels today are close to those of the mid-1970s. This near-steady state is supported by student graduation trends at the larger departments (Fig. 2). However, there are considerably more departments awarding degrees in the field today than in the 1960s and 1970s; many of these additional departments are small with five or fewer atmospheric sciences faculty.

3. Employment trends

Have the number and types of jobs in meteorology and related disciplines changed during the past few decades and what are the probable trends? Hanson (1993), in a study of the AMS Employment Announcements from 1981 to 1991, found that the number of advertised positions grew throughout the mid-1980s but declined in recent years. Following the criteria used by Hanson, his analysis has been extended through 1994. The results, presented in Fig. 7, show that the total number of positions advertised each year was relatively constant (~200) during the first half of the 1980s but then nearly doubled between 1986 and 1988, with the largest contributor being a substantial increase in private sector employment. Subsequently, the number of job offerings declined slowly through 1990, followed by a relatively rapid decrease in the levels of the early 1980s in 1993 and 1994. Figure 8 uses the same AMS job dataset to present the changing job market for tenure-track faculty positions in the atmospheric sciences. In this figure, monthly variations in faculty job advertisements are shown for two periods: 1981–91 and 1993–94. One is struck by the considerable decline in the number of tenure-track positions per year and the different monthly modulation when the two periods are compared: during the last two years, faculty advertisements were most frequent in September, in contrast to the winter maximum of the previous 10-year period.

Fig. 6. Frequency distributions of the numbers of institutions providing degrees at the (a) bachelor’s, (b) master’s, and (c) doctoral degrees for 1991–93.
Changes in the NWS have had profound effects on employment in the atmospheric sciences. During the late 1980s and the first half of the 1990s, the NWS proceeded with its modernization and restructuring program, in which the number of forecast offices will more than double and the technological base of the organization will be updated with new Doppler radars, satellites, surface-based observing systems, advanced data display systems, and updated computer resources. To support the modernization, the NWS substantially increased its hiring of meteorologists during the late 1980s, ramping up from approximately 80 to over 200 new hires per annum (Fig. 9). NWS hiring peaked in 1994 and declined substantially in 1995. Because a large number of interns were hired during the past few years as well as the reduction in NWS responsibilities in agricultural and fire-related forecasting, hiring is now planned to be at a very low level (~25 per year) during 1996 and 1997. It is hoped that by 1998 NWS hiring will revert to a replacement level of ~100 per year. NWS employment is of particular importance because it hires most of its new employees directly out of college, providing them with crucial experience and additional training.

A key component of the NWS restructuring effort has been the placement of a Science and Operations Officer (SOO) at each NWS forecast office. Hiring of these individuals, who often possess graduate degrees, increased rapidly from 1992 to 1994, reaching a maximum of ~55 individuals in 1994 (Fig. 10). However, most SOOs had previously been employed within the NWS. SOO hiring will decrease rapidly during 1995 and 1996 to a replacement level of approximately 10 individuals per year.

5 The total number of NWS offices will, in fact, decline.

6 The NWS employment figures were supplied by Leroy Spayd Jr., National Weather Service, Silver Spring, Maryland.
Another major employer of meteorologists in the federal government is the Department of Defense, the largest component being the Air Weather Service of the U.S. Air Force. As shown in Fig. 11a, the number of available air force weather officer positions per year declined during the mid-1980s and has been approximately steady over the past five years at roughly 65 hires per annum. The number of navy personnel involved in meteorology has declined during the past five years and is planned to be steady state for the remainder of the decade (Fig. 11b).

One sector of the atmospheric sciences that has enjoyed considerable growth during the past few decades is the private component, which ranges from weather forecasting companies and data providers to television weathercasters, air and environmental quality firms, and forensic meteorologists. To illustrate the growing importance of the private sector, Table 2 presents statistics given by Stephens and Kazarosian (1992) that compares the principal employment of the responding AMS members for 1975 and 1990. Major trends include a substantial decrease in the percentage of military and university/college personnel and the doubling in the percentage of private sector meteorologists. One measure of private sector growth is the number of announcements in the professional directory at the back of each issue of the Bulletin of the American Meteorological Society (Fig. 12). This directory is dominated by consulting meteorologists who specialize in air quality modeling, forensic applications, and specialized forecasts. Following a period of relatively steady growth during the 1950s and early 1960s (from 11 to 40 announcements), there was a period of rapid growth, with only a brief pause from 1979 to 1983. During the past eight years, there has been only minimal growth in the number of such advertisements.

During the past year, the AMS distributed a survey to private sector meteorologists. Based on 374 responses from 262 companies and 112 individuals, D. Houghton (1995, personal communication) completed an initial analysis of the replies, which he estimates represents 32%–42% of the meteorological private sector. Important findings relevant to education and employment issues include the following.

- Private sector companies generally expect growth over the next 10 years with half predicting expansion of at least 10%, 44% expecting conditions to remain the same, and only 6% foreseeing a decrease of at least 10%.
- Most (90%) companies require at least a B.S. degree, with very few indicating a requirement for a

### Table 2. Comparison of 1975 and 1990 “Principal Employer” responses based on data presented in Stephens and Kazarosian (1992) and Kellogg (1977).

<table>
<thead>
<tr>
<th></th>
<th>1975</th>
<th>1990</th>
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<tbody>
<tr>
<td>Federal government</td>
<td>30.9</td>
<td>28.3</td>
</tr>
<tr>
<td>Military</td>
<td>11.6</td>
<td>6.7</td>
</tr>
<tr>
<td>State and local government</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>University/college</td>
<td>27.1</td>
<td>22.4</td>
</tr>
<tr>
<td>Nonprofit/precollege schools</td>
<td>6.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Private sector:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry/consulting/broadcast</td>
<td>16.9</td>
<td>33.1</td>
</tr>
<tr>
<td>Other</td>
<td>3.6</td>
<td>4.2</td>
</tr>
</tbody>
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The numbers shown are the percentage of those responding for each survey.

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7 The index plotted is the average of the number of advertisements found in the January and June issues of each year checked (only every four years were examined). A spot check revealed that there is very little month-to-month variability in the number of such professional advertisements.

8 This survey was sent out to 1147 addresses representing 606 TV Seal Holders, 417 Certified Consulting Meteorologists, 68 Radio Seal holders, and 54 corporations.
more advanced degree (13% and 6% for M.S. and Ph.D., respectively).

- During the past year, 40% of the companies had no new positions and 54% had entry-level positions available.
- During the next year, responding companies expect to hire 179 meteorologists at the entry level.
- A large number of nonmeteorologists work on weather-related activities, implying some potential for expansion of employment opportunities.

To get some gross measure of overall trends in employment, Fig. 13 presents the number of new jobs derived by adding the past and present hiring of the NWS, the Air Weather Service, and the positions advertised in the AMS Employment Announcements. Although some meteorologist positions are undoubtedly not included in this summary, it probably represents a majority of the positions available in the field. Important features of Fig. 13 include the rapid increase in the number of new jobs between 1986 and 1990 and the subsequent modest decline.

4. An analysis of past and future employment trends

The information provided in the previous sections suggests why the supply of atmospheric scientists roughly balanced the available positions for several decades and has worrisome implications for atmospheric sciences employment during the next few years. During the 1980s, unemployment in the field was kept relatively low by several factors, including the following:

- a rapid escalation of hiring at the NWS to provide staff for modernization and restructuring;
- an increase in the number of military meteorologists associated with the defense buildup of the early and mid-1980s;
- a considerable increase in the private sector, including a rise in the number of TV weathercasters, increased numbers of private sector firms, and more companies providing services to federal agencies such as NASA and NOAA;
- substantial increases in research funding, especially in the areas of climate and global change;
- the retirement of WWII-era meteorologists; and
- continued growth in environmental consulting firms as a result of the environmental legislation of the 1960s and 1970s such as the Federal Clean Air Acts of 1963 and 1970.

From 1990 to 1994, employment opportunities slowly diminished—particularly in the government and university sectors—as federal research funding leveled off (in constant dollars), military employment gradually declined, the number of retirements of WWII-era meteorologists diminished, and the number of students graduating in the field increased modestly. Competition for jobs was also enhanced by the pool of well-educated Russian émigrés that came on the world market with the demise of the Soviet Union. Key factors that have kept the situation from worsening further during this period include increases in NWS employment (which peaked in 1994, Fig. 9), continued expansion of the private sector, and modest growth in the number of postdoctoral positions.

It appears that the employment situation will likely worsen in the public and university sectors during the next few years if research funding tightens further (which is highly probable), NWS hiring drops (a certainty), and student graduation rates remain near current levels. In fact, a deterioration in job availability is now becoming increasingly obvious. Because of a
freeze in NWS hiring, increasing number of graduating seniors are now finding it difficult to secure their first professional job. Increasingly, recent Ph.D.s in our field are being employed in temporary postdoctoral positions and are finding the search for permanent positions more difficult. Faculty positions, when available, are being swamped by large numbers of applicants.

With employment growth in the public sector unlikely in the near or distant future, the only short-term hope for growth lies in the private sector, which indeed has shown considerable expansion during the past decade. Is further private section growth a reasonable expectation? During the past few years, a period of both economic expansion and the availability of new technologies for weather observing and forecasting, the *AMS Employment Announcements* (Fig. 7) showed a decline in private sector job advertisements, and the number of announcements in the AMS Professional Directory remained nearly constant (Fig. 12). Could it be that much of the private sector expansion of the last decade was in support of the nearly completed National Weather Service modernization, increases in NOAA- and NASA-sponsored private sector research or support services, and the growth in the number of television weather broadcasts, all of which are now in decline or steady state? In that case, a net increase in private sector employment might not be expected in the near future. A more optimistic note is provided by the AMS private sector survey mentioned above (D. Houghton 1995, personal communication), which suggests continued modest growth; the fact that several private weather forecasting firms have recently enjoyed considerable expansion (M. Smith 1995, personal communication); and the positive implications for the private sector of the shrinking role of the NWS.

Although the above discussion raises some concerns about employment prospects during the next few years, there are trends and opportunities that could have a positive impact on atmospheric sciences employment in the longer term. First, atmospheric scientists that began their careers during the rapid expansion of the 1960s will begin retiring during the first decade of the twenty-first century, releasing their positions—assuming, of course, that they will be replaced. Second, the need to educate large numbers of children of the baby boom generation may stimulate the growth of colleges and universities, providing additional faculty and staff positions. Certainly, the need to educate society in general regarding scientific and technical issues has never been greater. Atmospheric scientists can contribute to this educational enterprise as teachers (in secondary schools and community and four-year colleges) or in other roles. Third, a relatively low percentage of media weathercasters possess atmospheric sciences degrees; additional training in broadcast presentation skills might help secure increased numbers of jobs for our students in this industry and improve the weather information...
provided to the public. Fourth, there are great opportunities for improving mesoscale forecasting as a result of new observing technologies (e.g., NEXRAD Doppler radars, radar wind profilers), rapid improvements in mesoscale modeling, and significant enhancements in our knowledge of local weather features. If the atmospheric sciences profession can communicate this potential to society, it should be possible to create a growing industry, based on a partnership between the university, government, and private sectors that would provide regional diagnostic and forecasting services.

Fifth, if global warming is convincingly demonstrated, additional research funding would probably flow into the discipline and interpretative services for industry, government, and the general public could develop. For example, services that provide insights into the regional implications of the new climatic regime might flourish.

There are also factors that could worsen the future employment situation. First, with the passing of the mandatory retirement age, individuals who would have retired at 65 or 70, now have the option to remain in the work force. How many will thus delay retirement is unclear; however, it is the author’s observation, based on an admittedly small sample, that most individuals still retire by age 70, with a few remaining active into their 70s. Second, it appears increasingly likely that research and operational budgets at NASA, NOAA, and even NSF will fall short of even recent budget projections, with decreasing funding levels in terms of constant dollars (Lawler 1995).

5. What should be our response?

As noted above, there are a variety of signs that the job market in atmospheric sciences has tightened, at least in the university and public sectors. In light of this tightening job market, the stagnation of federal support of meteorological research, the end of the rapid hiring phase of the NWS modernization, and other indications of slower employment growth outside of the private sector, are we graduating too many students in the atmospheric sciences? Should we take additional steps to help our students secure employment in a rapidly changing employment and professional environment? Attempting to answer these questions, different approaches may well be appropriate at the undergraduate and graduate levels.

a. Undergraduate level

As noted above, the job market for undergraduates is undergoing a transition, partly because NWS hiring has been substantially reduced. Furthermore, because of the overall tightening of the job market, those with graduate degrees are increasingly competing with bachelor’s candidates. This phenomenon has become evident in the NWS, where increasing numbers of forecast interns are entering with master’s degrees (C. Hill, NWS area manager for Washington, 1995, personal communication). How should atmospheric sciences and meteorology departments respond?

At the undergraduate level, one can argue persuasively that there is no need to limit the number of atmospheric sciences/meteorology majors, since a properly structured atmospheric sciences program is a good base for a variety of careers, such as environmental consulting, computer programming, and aviation, to name only a few. By encouraging our undergraduate students to strengthen their backgrounds in subjects such as communication, atmospheric chemistry, boundary layer meteorology, and computer programming, we could enhance their potential for employment in areas of future growth. Furthermore, as found in the AMS private sector survey (D. Houghton 1995, personal communication), most of the new positions in the private sector only require a bachelor’s degree. Finally, undergraduate degrees in many, if not most, fields do not guarantee jobs in the respective disciplines. Few history majors complain when they do not secure jobs in historical research or teaching.

In the past, when most undergraduates went on to work for the NWS or the military, the educational requirements of the potential employers were clear and it was relatively easy for universities to structure their academic programs. Today, the academic community must respond to more diverse needs, preparing students to follow a wide variety of career paths and providing students with strong, proactive advising. However, such a response is predicated on faculty members first educating themselves about the backgrounds these employers require for potential employees.

It is incumbent upon atmospheric sciences departments to be honest with prospective majors regarding the tightening of the overall job market, as well
as noting those areas most likely to provide fruitful job prospects. Unfortunately, few departments track their undergraduates’ postgraduation employment, and there is no communitywide effort to document the employment history of undergraduates after graduation. An organized effort to produce such an employment database [perhaps guided by the University Corporation for Atmospheric Research (UCAR) or the AMS] should be a priority.

b. Graduate level

The situation on the graduate level is different and more problematic. There is some evidence that we are graduating too many atmospheric scientists for the current job market and that this overproduction, particularly of doctoral degrees, may have a negative effect on the long-term health and productivity of the discipline:

• The graduation of an excessive number of researchers may be a poor investment of increasingly limited research dollars. With an annual salary cost of approximately $30,000 (including overhead), a typical Ph.D. student who takes six years to graduate can easily cost a funding agency one-quarter of a million dollars when all expenses (e.g., equipment, associated faculty advising time) are included.

• Since Ph.D.s are the seed corn of the field, excessive production can worsen employment in the long term by increasing graduation rates in the future. However, this factor is partially mitigated by the limited number of university faculty positions (i.e., a large fraction of the Ph.D.s will not have students).

• The combination of increasing numbers of researchers and stagnant funding has already resulted in greater competition for available funds. Although moderate competition is healthy, when the pool of support gets too small, individual researchers are forced to spend ever increasing amounts of time maintaining their funding as grant sizes and acceptance rates decrease. Such time usually comes out of productive research and teaching. At NSF’s Atmospheric Sciences’ Division, the median annual award (adjusted for inflation) has dropped from approximately $100,000 during the early 1980s to about $84,000 in 1994, while the percentage acceptance rate has remained relatively steady (S. Nelson 1995, personal communication).

• Excessively tight money discourages new and innovative work, encouraging investigators to remain with more traditional lines of inquiry, and putting individuals without a track record at a disadvantage.

• As the job market tightens, the most talented and perceptive students may sense the poor employment situation and go into other careers. Whether this effect has contributed to the decreasing percentage of American students at U.S. atmospheric sciences departments (as well as other scientific disciplines) is a matter of debate.

If we are in fact overproducing graduate students, there are several ways in which the problem might be addressed: reduce our student output, provide prospective and current graduate students with better information on employment and alternative career paths, broaden the graduate curriculum to ensure that each student has the flexibility needed in a dynamic and changing employment environment, and finally to cooperate as a discipline to produce job growth by finding new applications for atmospheric information.

1) REDUCTION OF GRADUATE STUDENT PRODUCTION

Considering the trends described above, it would appear that a modest reduction in the number of graduate students is warranted (perhaps 10%–25%), with the savings being applied to additional postdoctoral and permanent positions. The universities themselves could take the lead and voluntarily reduce the size of their graduate programs, an approach that has already been taken by several departments. Reduced federal research funds is already resulting in a constriction of graduate student support at several federal agencies, and thus some adjustment in graduate student output will automatically occur as funding declines. However, it is likely that the pressures and inertia of the present system are sufficiently strong that the intervention and management by funding agencies and community leadership (such as UCAR or AMS) will be necessary for a timely and effective response. For many years, agencies such as the NSF have given priority and emphasis to the support of graduate students. This policy needs to be modified. However, it will take several years for a reduction in the graduate student population to be felt in the employment market since master’s degree programs typically take two–three years and doctoral degrees often require four–seven years. Thus, during the first few years only the redirection of funding from graduate students into more permanent positions will help mitigate the employment situation. There are several approaches that
funding agencies could apply to reduce the number of graduate students they support.

- Currently, there are several atmospheric sciences faculty members at departments around the country who supervise 5–10 graduate students; some faculty members have as many as 12–15 students. Students working under such overloaded advisors may receive insufficient guidance, often resulting in delayed graduation and inferior theses. A related question is how many times should a professor reproduce? A number of professors during their professional careers have graduated 10 or more students with Ph.D.s. Such fecundity can result in rapid growth in the number of researchers. Considering the considerable drawbacks of a professor supervising more than four or five graduate students at a time, only in exceptional cases are greater numbers of students per investigator warranted (e.g., the need to support and use a large and unique facility). Thus, as a first step, funding agencies should consider the total number of students supported by principal investigators from all sources and discourage ratios of more than five to one.

- As noted by W. Bowen, president of the Andrew W. Mellon Foundation, there has been an excessive proliferation of Ph.D. programs that graduate only a few students per year (Moffatt 1994); he suggests that such very small programs lack the critical mass to do the job well. There are a number of small programs, many with less than five faculty members, awarding graduate degrees in the atmospheric sciences (Curricula in the Atmospheric, Oceanic, Hydrologic, and Related Sciences 1994). These small groups usually offer only a limited range of courses and frequently lack the infrastructure necessary for providing a broad, state-of-the-art graduate education in atmospheric sciences. Such a broad background is of particular importance today, because it provides students with the flexibility to move within a tight job market and to participate in increasingly important interdisciplinary research. Because of a general reduction in the pool of prospective American students, these smaller departments have increasingly relied on foreign nation-

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10 As noted by a reviewer of this manuscript, there are also positive aspects to large research groups. Such extended groups can contain a critical mass for attacking particularly difficult or complex problems, and the interactions between the students can be very fruitful.

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11 This statement is based on discussions with faculty at a number of departments and from a detailed perusal of the Curricula in the Atmospheric, Oceanic, Hydrologic, and Related Sciences for the past decade.
graduate departments should examine and revise their curricula to ensure that their students are given the broad background required to take advantage of a dynamically changing employment environment. In addition to the provision of a more comprehensive graduate education, departments should furnish their students with information about potential employment in related fields.

4) EXPANSION OF EMPLOYMENT OPPORTUNITIES

As noted in section 4, there are several areas in which the discipline could promote job growth by applying new observing and modeling technologies to societal problems. Examples included the application of radar data to water management and transportation, high-resolution modeling of pollutant dispersion and precipitation in areas of orography, and the application of general circulation modeling experiments to help weather-sensitive industries understand the regional implications of global climate change. In general, such expansion of opportunities will require cooperative, working relationships among the academic, government, and private sectors. For example, the U.S. Weather Research Program could play a major role in developing the scientific and technological infrastructure required for a new generation of meteorological applications and services. Employment opportunities can also be promoted by ensuring that weather-sensitive industries understand the potential value of staff meteorologists.

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