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Wanted: More Ph.D.s

Graduate enrollments in the atmospheric sciences

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A recent survey of UCAR member institutions shows reason for concern about a possible decline in the number and quality of applicants entering graduate studies in the atmospheric and related sciences. If reported trends continue we may face a shortage of qualified Ph.D. graduates in the fieldin the next decade.

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During the past two years, the UCAR Board of Trustees and other members of the UCAR university community have become increasingly concerned about the number of students applying for graduate school (Anthes, 2000a). A number of us have seen the pool of applicants shrink at our own Ph.D. programs in recent years. Furthermore, participants in the 1999 UCAR Forum on the future of the atmospheric sciences confirmed that there is a serious problem regarding the quantity and quality of students entering the atmospheric and related sciences (including oceanography, space science and earth science). In a subsequent UCAR survey on broad topics, conducted during June and July of 2000, we received more comments on the quantity and quality of graduate students than on any other issue (Anthes, 2000b). Apparently many university departments around the world are experiencing similar difficulties recruiting highly skilled students in the environmental sciences (Brasseur, 2000).

Anecdotal evidence suggests that this decline has led to increased competition nationally for good students, a shortfall of graduate students to assist in teaching, and a smaller pool of students to contribute to the university research efforts. If the decrease is truly widespread and persistent, the number of PhD graduates could be insufficient to meet national needs in the near future. To gain a more objective view of the situation, we surveyed UCAR universities specifically about this issue and investigated related statistics available elsewhere. To our knowledge, this is the first such study of the Ph.D. pipeline in atmospheric sciences in recent years, and the results reinforce our concern. The community may face a significant shortfall in Ph.Ds by the year 2011.

UCAR Enrollment Survey

Our questionnaire, posted on the web in April 2000, requested data from UCAR member institutions on graduate student enrollments from the 1995-96 academic year to 1999-2000. While five years is a short period for such a study, we wanted data that were relatively easy to access to assure a large response. We asked for the number of students who applied, who were admitted, and who actually entered the program, as well as for the GRE scores of the admitted students. The students who matriculated were separated into two groups: those with and without financial support. In addition, we asked respondents to rate on a scale of 1-5 how significant they felt this graduate enrollment problem to be, with 1 being insignificant and 5 being very significant. We promised to keep the identity of the respondents confidential.

Out of 63 institutions contacted, 36 responded–a rate of 57%, which is good given the relatively large amount of effort required. The average rating on the 'significance' question was 3.25 and the median was 3.75, indicating that the respondents considered this issue to be an important one, but not yet extremely serious. For the 5-year period, the annual average of the total number of students applying to graduate schools at the 36 institutions reporting was 2765, and the average number entering graduate school was 388.

For all schools combined, applications declined over five years at an average rate of 8.7% per year, admissions decreased by 1.3% per year, and 3.2% per year fewer students entered the programs–trends computed by least -squares fit to the data in fig. 1 (see also table 1). We stratified the data by school size by sorting the schools in order of the average number of students who entered in the 5 years. We divided the respondents four groups, each with roughly one quarter of the total number of entering students[1]. The 3 largest schools admitted a fourth of the total number, the next group of 6 schools another quarter, the next 8 another quarter, and the smallest 19 another quarter. We refer to the four groups here as *largest*, *large*, *medium,* and *small*. The average numbers of entering students per institution for the four groups were 30.7, 18.0, 11.4 and 5.0.

Because only 57% of the universities contacted responded, the total numbers of students applying to, accepted by and entering the departments of atmospheric and related sciences at UCAR universities are larger than these numbers. We multiply these numbers by 1.75 to estimate the totals for the entire UCAR community, on the assumption that the sample is representative.

The 8.7% decrease per year in the number of applications represents a decline of about 240 applications per year at the responding schools alone. The annual average decrease in the number of entering students is about 12. The rate of decrease of applications varied by group, but all groups experienced negative trends. Admissions and matriculations show small and probably insignificant positive trends for the *largest* and *small* schools, but negative trends overall.

Because the number of applications is decreasing faster than the number of admissions, the universities are having fewer choices and are therefore possibly becoming less selective (fig.

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[1] One school didn't report the number of entering students. For the sake of grouping only, 0.4 times the number admitted was used for this school. The factor 0.4 is the average ratio for all schools.

2). The GRE scores, however, reveal no clear temporal trends. For all schools combined, variations from the mean values shown in Table 2 over the five years are just a few percent.

The scores in Table 2 would represent roughly, the upper 32, 17, and 33% of all those taking the GRE and indicating earth, atmospheric, and marine sciences as their intended field (ETS 2000; Table 4). Interestingly, the average scores of students heading into the earth, atmospheric and marine sciences are nearly identical to scores of those going into biological sciences. However, the average quantitative scores are about 80 points (~13%) below the scores of those in physics, chemistry or computer sciences (ETS 2000; Table 4.).

Alarming Signs

Even though GRE scores don't yet show consequences of a smaller applicant pool, there are general trends in the sciences that may intensify the size and impact of a future shortfall of new Ph.Ds. The generally unsatisfactory state of science education in this country is one of these trends. The proportion of 24-year-olds with degrees in the natural sciences or engineering was near 5.5 % in the United States compared with 9.5 % in the United Kingdom, 8.9 % in South Korea, and 8.2 % in Germany. Japan and Taiwan are also ahead of the U.S. in this measure. Of the same group of six countries, the U.S. held second place on this score in 1975, slipping to last by 1997 (NSB, 2000a, Fig. 4-15.).

Another relevant indicator is the number of bachelor's degrees awarded in various disciplines. The number of graduates in physical sciences in 1995 was about 20% lower than in 1981 even though the overall number of bachelor's degrees grew by nearly 20% over the same period (NCES 1998, Indicator 29). This was the only decreasing field in the survey, which ranged from the humanities to engineering. A small bit of positive news can be added to this: after ten years of steady decline, the number of physics bachelor's degrees remained unchanged in 1998 from the previous year (AIP 2000).

Fortunately the decline in numbers of physical science graduates is not uniformly duplicated in trends over the past two decades in the number of graduate degrees awarded in the atmospheric and related sciences (NSB 2000b, Tables 4-23 and 4-25; NSF 2000b, Tables 12, 19, 41 and 43). As Fig. 3 shows, the trends are quite different in atmospheric sciences than in oceanography. A long-term upward trend in atmospheric science doctoral degrees appears to have been accompanied by an equally strong downward trend in M.S. degrees earned.

The trend in Ph.D.s since 1989 is an average annual increase of 3.8%, but the last two years (1997-98) are down for the Ph.D. degrees. Trends are more complex for graduates in oceanography, but these numbers also decreased in the last two or three years. The rate of increase of Ph.D.s in atmospheric science was considerably greater than the increase of earth-atmosphere-ocean science Ph.D.s as a whole or for physical-earth-mathematical-ocean-biological sciences overall (fig. 4). The decreasing rate of growth in the latter part of this period is also evident for the other groups.

The AMS-UCAR Curricula Guides for 1998 and 2000 (Curricula 1998, 2000) provide independent data for the number of BS, MS and Ph.D. degrees for two-year periods centered around 1996 and 1998. These data (Table 3) complement and extend the NSF data, although they are not exactly comparable because the time periods and schools sampled are not identical and the AMS-UCAR data include graduates in oceanography, hydrology and in some cases earth sciences as well as atmospheric sciences. Nevertheless, the message from the data in Table 3 is consistent with that from the NSF data. There is a significant decline in the number of undergraduate and MS degree over the period 1996-2000.

Fig. 5 shows the trends in the numbers of doctorates in the earth-atmospheric-ocean sciences that were granted domestically to U.S. citizens and permanent residents and to non-U.S. citizens with temporary visas (NSF 2000a, Table 3). Since 1994 the former group decreased moderately and the latter group grew more sharply, but overall the 10-year trends are close to insignificant.

An Aging Science

Another general trend that could affect a future Ph.D. shortfall is demographic. The sciences generally are aging. As Fig. 6a shows, the percentage of full-time doctoral faculty in science and engineering under age 45 has declined from 62% in 1973 to 38% in 1997; fig. 6b shows this shift in age distribution as well. The percentage of faculty under 35 has decreased even more, from 26% in 1973 to 8.3% in 1997. The same data show that the average age of science and engineering faulty has risen from 42.5 in 1973 to 48 years in 1997 (fig. 7).

The most recent data available (fig. 8) show some similar trends for earth-atmospheric-oceanic sciences (NSF 1997, Table 15; NSF 2000c, Table 15; and NSF 2000d, Table 6). The total number of Ph.Ds in the earth/atmosphere/ocean sciences increased from 15,580 to 18,360 (17.8% or about 4.5% per year) from 1995 to 1999, but this growth was not even across all age groups. The under-35 year-old category decreased while the 35-39-year-old category increased in 1995-99. This may reflect a trend of students being somewhat older when embarking on Ph.D. programs and/or a longer time spent completing the program. In the 45-54-year-old groups, the relative proportions decreased, but the actual numbers increased during the period. The 55-and-older groups increased over the period. There is a small but distinct shift in age distributions, amounting to 0.9 years in average age over the 4 years (fig. 9). The lower panel (NSB 2000b, Tables 3-19 and 6-25) illustrates that there is no appreciable difference between the ages of the overall science and engineering doctoral workforce and the full- time Ph.D. faculty holding in the earth-atmospheric-oceanic sciences.

The aging of Ph.D. scientists overall in this country will continue in the near future unless more young Ph.D.s enter the field. The spike in the 55-59-year age group portends a significant increase in average age over the next ten years or so. Assuming that younger scientists contribute much of the creativity in the field, these trends suggest that the vitality of the scientific workforce may ebb. They also suggest that retirements will increase rapidly in the next decade, causing a shortfall of Ph.D.s unless the number of Ph.Ds entering the field increases.

If the 5-year decline in graduate applications to departments of atmospheric science becomes widespread and persistent, the implications aresignificant and disturbing and there maynot be enough doctorates to meet needs. In an extreme scenario, the viability of some departments may be threatened. More generally, the opportunities and challenges presented by the environment, where the atmospheric sciences play a critical role, demand a steady supply of young, energetic, and creative talent.

Modeling Future Needs

We have developed a simple model (see sidebar) that estimates the need for future Ph.D graduates for the field given a number of quantitative assumptions that can be varied to produce different scenarios. Obviously any predictions of this type are uncertain, but the scenarios are instructive. For the base case we assume that the need for Ph.Ds will grow by 15% over the next decade (NSB 2000b, Appendix table 3-28, p. A-208). The different assumptions and results for three scenarios are listed in Table 4. The number of new Ph.Ds needed over the next decade varies from 675 in the least-need case to 1,642 in the greatest-need case.

Another way to look at the situation is to interpret the relatively small variabilities of the curves in Fig. 9 as indications of a slowly varying age distribution. If the age distribution were steady state, then, the slope of the lines in Fig. 9 are equivalent to the rate of flow into and out of the population. This slope is 3% per year, which implies that about 3% of the total number of Ph.Ds in the field must enter and exit each age interval. According to this rule, for a steady state total of 2,700 Ph.D atmospheric scientists, about 81 new Ph.Ds would have to enter the field each year. This number is between the base case and "least need" scenarios shown in Table 4. The distribution curves are slightly steeper, up to 3.8%, if data are used for employed doctoral scientists only. However, if one assumes no change in retirement practices and in other factors governing employment, then the total population of degree holders is the relevant population to consider here. If the number of Ph.D scientists grows, then additional assumptions will have to be made about the source of that growth, namely whether it consists of new graduates or transfers from other fields. Maintaining the recent (past 4 years) rate of increase of about 4.5% per year (Fig. 8) entirely from new graduates would require 120 new PhDs per year in addition to the 81 representing the replacement rate; clearly this is an upper limit estimate.

The average number of Ph.D graduates per year in recent years (1995-1999) varied between 100 and 150 (fig. 3) and current projections for the next few years are also in this range (Table 3b). If this rate persists for the next decade, there will be a sufficient number of Ph.Ds by the year 2011 for the base and least need cases. Should either the number of Ph.D graduates continue to decline or the "greatest need" scenario occur, however, there could be a significant shortfall in the number of Ph.D.s.

Implications and conclusions

Monitoring graduate school application and entry numbers can reveal trends well ahead of measures (such as graduation rates) that are normally used to examine the supply of a research workforce. This paper can be considered a baseline study to be updated in about five years, and UCAR will continue to monitor the situation through annual surveys of members.

In the meantime, short-term trends and projections into the future are highly risky. Only a few years ago, the UCAR community was worried about overproduction of graduate students (Mass, 1996). The universities and the National Weather Service were hiring very few new graduates. It looked like there might not be enough suitable jobs for the large and increasing number of graduates in the atmospheric and related sciences. Some people even suggested that departments should limit the number of graduates. The community eventually decided that it was not up to the universities to artificially limit graduates and that growing opportunities in the private sector could make up for the reduced hiring by the universities and the government. This decision may turn out to have been wise, but not necessarily for the reasons given at the time.

It is important to understand the reason for the drop in graduate school applications and, if it continues, to address the underlying causes. As discussed at the UCAR Fora in 1999 and 2000, more practical issues, such as the long time and great effort needed to obtain a doctorate and the relatively meager financial rewards at the end of the process, may be among the most important reasons for the declining interest. For example, the salaries of new doctorates in the earth and space sciences run considerably below those in other disciplines (CPST 1998; NSF 1997, Table F-1.).

Whatever the reasons for the decline, we as a community should seek ways to increase the number of qualified applicants. Because the number of atmospheric scientists required under any reasonable scenario is small compared to the total number of students in undergraduate education, a modest increase in the effort to recruit students from other disciplines could have a major impact in a relatively short period of time. An important aspect of any strategy is to increase the diversity in our field. Caucasian males have long dominated the field, but compose only 33% of the primary and secondary students in the United States. In addition to all the other good reasons for increasing diversity, the demographics say we need it. UCAR will respond to these challenges by increasing efforts to recruit students from diverse backgrounds into the field.

The intellectual excitement of the atmospheric sciences, the importance of the field to society, and the availability of powerful observational and theoretical tools to advance the science have never been higher. Our community is not communicating these opportunities to enough students.

SIDEBAR: Modeling Ph.D. Demand

Let N_t be the total number of Ph.D.s needed in M years, N_p the total number of Ph.Ds presently in the field, and N_r the number of Ph.D.s retiring or leaving the field for other reasons in M years. Then the number of new Ph.D.s needed over the next M years, N_g, is

$$N_g = N_t - N_p + N_r \qquad (1)$$

The total number of Ph.Ds needed in M years, N_t, is given by

$$N_t = N_p\,(1 + P_n) \qquad (2)$$

where P_n is the assumed percent increase (or decrease) in the need. The number of retirements, N_r, over the next M years can be estimated as a function of the number of people in various age ranges times the probability that the people in this range will retire during this period. For example,

$$N_r = [P_{R<56} \times P_{<56} + P_{R56\text{-}65} \times P_{56\text{-}65} + P_{R66+} \times P_{66+}]\,N_p \qquad (3)$$

where P is the percentage of N_p in the three age ranges and P_R is the probability of retirement of the people in these ranges.

We create three scenarios based on different, but plausible, assumptions about the need for Ph.Ds in 2011 using the above model. We take N_p to be the number of PhDs in atmospheric sciences in 1997, estimated by NSF (1997) to be approximately 2,700. From the 1997 age distribution of all science and engineering Ph.Ds (NSB 2000a, Fig. 3-13, p 3-23) we take the percentage of N_p presently 66 years old or older to be 5% and the percentage of N_p in the age range 56-65 to be 21%, which leaves 74% of N_p aged less than 56 years.

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