

Bachelor's Degree in Atmospheric Science

Approved by American Meteorological Society Council

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1. Introduction

The primary purpose of this statement is to provide guidance to university faculty and administrators responsible for undergraduate programs in atmospheric science. (Within this document, “meteorology” and “atmospheric science” are considered equivalent.) This statement describes the minimum curricular composition, faculty size, and facility requirements recommended by the American Meteorological Society for an undergraduate degree program in atmospheric science. The AMS encourages colleges and universities to develop healthy and viable programs that exceed the minimum requirements. This statement also provides information to help students explore educational alternatives in atmospheric science.

The program attributes listed in Section 2 are essential for all atmospheric science programs. As summarized in Section 3, students who have completed the requirements for an undergraduate degree should possess a core set of competencies resulting from completion of prerequisite courses as well as those in atmospheric science. Additional coursework that may be helpful for specific careers is suggested in Section 4. Programs are encouraged to allow specialization in one or more of these specific areas.

Recognizing the emergence of online learning in the atmospheric sciences, the Council encourages such programs follow the guidelines here as closely as possible.

2. Program Attributes

a. Faculty

There should be a minimum of three full-time regular faculty holding doctoral degrees and with appropriate expertise sufficient to address all the subject areas identified in Section 3. This recommendation assumes a faculty teaching load of three or more courses per semester. In departments where atmospheric science faculty are expected to carry out active research programs, the minimum number of faculty should be increased in relation to the university's research expectations. Faculty sizes larger than the minimum are generally expected, given the importance of our field within society, opportunities for collaborative research and teaching with other physical and environmental sciences, and the relatively high levels of external research funding available in the atmospheric sciences and related fields.

b. Facilities

Programs should have facilities that provide adequate classroom/lab space, computer-based/Internet access to weather and climate information (data and other resources), work areas and journal access for undergraduate research and independent study, and the resources necessary to provide hands-on outdoor learning opportunities.

c. Diversity

The number of students from traditionally underrepresented groups in the atmospheric sciences continues to be alarmingly low. Ideally, the faculty and students in atmospheric science programs should reflect the full diversity of the general population. Each program should develop and implement a strategy for recruitment and retention of diverse students and a diverse faculty.

d. Educational Goals

All atmospheric science degree programs are expected to provide students with opportunities for breadth and specialization through an appropriate mix of prerequisite, required, and elective courses. The main purpose of an undergraduate program is to prepare students to work as professionals in the field or to pursue graduate study. Increasing the number of members of society knowledgeable about atmospheric science is also an important goal for the profession, independent of the students' eventual careers. Along with particular subject matter considerations, courses should be designed to encourage students to develop the critical thinking, problem solving, reasoning, analytical, and communication skills that will provide them with the necessary versatility for long-term success as science professionals.

The objectives of a particular bachelor's degree program in atmospheric science at a college or university should be clearly defined by the faculty and openly shared with current and prospective students and potential employers. Programs are strongly encouraged to frame their objectives in terms of measurable learning outcomes that reflect the full breadth of the degree program and to systematically monitor their students' success in achieving those learning outcomes. Degree programs should allow graduates to pursue careers within atmospheric science or other closely-related environmental fields while providing a foundation upon which additional education, training, or specialization in science, policy, education, law, or other fields may be pursued.

Programs are strongly encouraged to actively instill in their students the principles of proper ethical conduct within their future professions, such as those listed in the AMS Guidelines for

Professional Conduct (see Article XII of the AMS Constitution, <http://www.ametsoc.org/aboutams/organizationpdfs/constitution.pdf>). Programs should seek to help students understand the application of weather and climate information in a broader context, from the public interpretation of weather forecasts to the policy implications of climate change.

3. Basic Components of an Undergraduate Degree in Atmospheric Science

a. Prerequisite Topics in Mathematics and Physical Sciences

These subjects/courses are prerequisites for the required topics in atmospheric science. While some topics may be incorporated into atmospheric science courses, the foundation of future atmospheric science learning should be built upon a set of six to nine prerequisite courses taught in their traditional departments. The mathematics and physics coursework should be that required for other physical science and engineering majors. The physics coursework must be calculus-based and must include a lab.

Mathematics

- Differential and integral calculus
- Vector and multivariable calculus
- Probability and applied statistics

Physics

- Fundamentals of mechanics
- Basic thermodynamics
- Electromagnetic radiation
- Electricity and magnetism

Chemistry

- Atomic structure and chemical bonding
- Properties of gases

b. Required Skills and Competencies

In addition to knowledge of specific topics in atmospheric science, competency in the following areas is essential. Opportunities for enhancement of these skills within discipline-specific coursework is strongly recommended.

Scientific Computing

- Experience using a high-level structured programming language (e.g., C, C++, Python, Matlab, IDL, or Fortran)
- Ability to apply numerical and statistical methods to atmospheric science problems

Oral, Written, and Multimedia Communication

- Ability to create and deliver scientific presentations using appropriate multimedia techniques
- Demonstrated effectiveness in oral discussion and interpretation of current weather events and forecasts
- Ability to write an effective scientific report
- Ability to effectively communicate with technical and lay audiences using scientific evidence

c. Required Topics in Atmospheric Science

The topics listed below should be addressed within the set of courses required of all atmospheric science students. These topics should be incorporated into the curriculum to ensure rigorous treatment while maintaining flexibility within the program as to exact course structure. Some of the topics below can be treated as entire self-contained courses, while others may take up only a fraction of a course.

Almost all of the topics listed below are best treated after students have taken most, if not all, of the listed mathematics and physics prerequisites. Some of the advanced meteorological topics require knowledge of differential equations, which may be obtained through a prerequisite mathematics course (as is presently required for federal meteorologist positions (see Appendix)) or through suitable mathematics instruction within a meteorological context. The general subject categories listed below are for organizational convenience, and individual programs should organize topics within and among courses, and establish learning outcomes, so as to maximize the educational benefit to students.

Meteorological Measurements

- Sensor performance characteristics and sources of error
- Quality assurance, standards, and evaluation of data
- Surface and upper-air weather instrumentation
- Principles and interpretation of weather radar
- Principles and interpretation of weather satellite data
- Profiling systems (radio frequency, acoustical, and optical)

Physical Meteorology

- Atmospheric thermodynamics
- Radiation in the atmosphere
- Cloud and precipitation physics
- Atmospheric electricity and optics

Dynamic Meteorology

- Governing equations
- Geostrophic, gradient and thermal winds
- Circulation and vorticity
- Quasigeostrophic theory
- Atmospheric waves
- Baroclinic and barotropic instability

Synoptic Meteorology

- Subjective weather analysis
- Objective weather analysis
- Predictability and chaos theory
- Structure of synoptic-scale weather systems
- Jet stream dynamics
- Cyclogenesis and frontogenesis
- Weather forecasting concepts
- Precipitation types and hydrometeorology
- Use of numerical weather prediction products in forecasting

Mesoscale Meteorology

- Air mass boundaries (fronts, drylines, and outflows)
- Mesoscale instabilities
- Fundamentals of the planetary boundary layer
- Mesoscale boundary layer phenomena
- Single, multi- and supercellular convection
- Mesoscale convective systems
- Severe weather
- Tropical cyclones
- Orographic mesoscale phenomena

Climate Dynamics

- General circulation of the atmosphere and ocean
- Regional climates and microclimates

- Intraseasonal and interannual climate variations, including El Niño/Southern Oscillation
- Long-range weather forecasting
- Climate data analysis
- Reconstruction of past climates
- Climate models
- Causes of past and future climate change

Capstone Experience

- Undergraduate research project, *or*
- Career-focused internship, *or*
- Capstone course

4. Beyond the Basics

In addition to the prerequisite courses and courses treating the required topics above, students should be required to take additional courses that allow for inclusion of topics relevant to regional needs, take advantage of faculty expertise, and allow flexibility in the formulation of degree programs by individual institutions. This additional course work can be specified or elective, depending upon the needs and requirements of individual programs. These courses may be designed for breadth, specialization, or both. Below are topics appropriate to some possible areas of specialization. Programs need not attempt to provide instruction in all of these specializations.

a. Graduate School Preparation

Students intending to continue their education with a graduate degree (M.S. or Ph.D.) before pursuing a career should consider including the following topics in their program of study:

- Ordinary differential equations
- Partial differential equations
- Linear algebra
- Computational fluid dynamics
- Research experience, including effectively communicating the results in writing, orally, and electronically
- Additional scientific computer programming

b. Weather Forecasting

Students intending to pursue careers as weather forecasters should consider including the following topics in their program of study:

- Additional topics in numerical weather prediction beyond those required, with emphasis on understanding the structure, assumptions, and limitations of the models and on ensemble forecasting
- Additional topics in remote sensing beyond those required, with emphasis on the function, limitations and usability of satellite, radar (including dual polarimetric radar), and lightning network data
- Geospatial information science (GIS)
- Boundary layer, micrometeorology, and dispersion processes

Students should also consider specialized preparation for one or more particular career paths within weather forecasting, as described in the following subsections.

(i) National Weather Service

Students pursuing employment with the National Weather Service (NWS) should take coursework that satisfies the federal civil service requirements for meteorologist positions (<http://www.opm.gov/qualifications/standards/IORs/gs1300/1340.htm>, reproduced here as an Appendix). Students may increase their chances of obtaining an entry-level NWS position through NWS internship experience, a graduate degree, or prior private sector or military forecasting experience.

Courses necessary to fulfill the federal civil service requirements for meteorological positions should be made available and identified as such to students, even if they are not required for completion of an undergraduate degree. If the offering of such courses is not consistent with the educational objectives of the program, the institution should inform prospective students that the completion of their degree will not be sufficient for employment as meteorologists with the National Weather Service and other federal agencies without additional coursework completed elsewhere.

(ii) Military

Military Weather Officers initially work in forecast-intensive assignments; then most enter a graduate school M.S. program and work in more management and leadership roles in the later stages of their military career. Students intending to enter the military as an Air Force Weather Officer or Navy Meteorology and Oceanography (METOC) Officer should consider including some of the course work outlined in section 4a (Graduate school preparation and

careers) in their program of study. In addition to the core meteorology degree requirements, additional study in physical oceanography, marine meteorology, acoustics, and hydrography would be helpful for those students most interested in the Navy METOC program.

(iii) Broadcast Meteorology

Besides forecasting ability, broadcast meteorologists need a combination of broadcasting ability and general scientific knowledge. For broadcasting preparation, a minor in broadcast journalism/communication is ideal, including work on broadcast newswriting, broadcast reporting and television/radio production. Students must be able to prepare high-quality demonstration weathercasts, and an internship at a television/radio station is strongly recommended.

General scientific knowledge is necessary because broadcast meteorologists often serve as the “station scientist,” reporting on a wide range of scientific stories. Introductory courses in environmental science, oceanography, geology, hydrology, and astronomy would provide a valuable foundational background.

In addition, students planning to pursue a Broadcast Meteorology career should become familiar with the requirements and procedures for gaining certification, such as the American Meteorological Society’s Certified Broadcast Meteorologist program (<http://www.ametsoc.org/amscert/#cbm>).

(iv) Other Private Sector Forecasting

Students interested in a forecasting career in the private sector should gain additional weather forecasting experience, including developing their skills and knowledge pertaining to the use of the tools of weather forecasting in the areas of computer-based graphical display systems, observational data, and models. A business minor, including topics such as marketing and management, may be useful.

(v) International Standards

The World Meteorological Organization (WMO) has set standards for education and training to become a WMO meteorologist in WMO Publication 258. By 2016 all personnel worldwide issuing official aeronautical meteorological forecasts will have to meet the standards in WMO 258. This document will be updated in 2011 but the current version is: (ftp://ftp.wmo.int/Documents/MediaPublic/Publications/WMO_258_Volume_I/WMO_258_Volume_I_en.pdf).

c. Air Quality and Environmental Science Applications

Careers in air and environmental quality are available in the public and private sectors. Specific jobs vary significantly and can include field measurement work, numerical simulations, data analysis, environmental reports, policy and planning, monitoring, and forecasting. A full year of basic chemistry, as well as exposure to atmospheric and environmental chemistry, are essential. A minor in chemistry or environmental chemistry is highly recommended. Other desirable topics include atmospheric aerosols, cloud and precipitation chemistry, boundary layer basics, the urban atmosphere, transport and diffusion theory, and regional air pollution modeling. Air quality equipment and monitoring and air quality forecasting are also useful topics for many potential jobs. Familiarity with GIS and other relevant tools is also valuable. Finally, interdisciplinary topics, such as interactions of the atmosphere with the environment (for example, deposition of pollutants and their effects), health effects of air pollutants, and environmental policy, are also appropriate.

d. Teaching

Students interested in becoming a middle or high school science teacher should investigate the particular educational requirements to be eligible for hiring in their preferred state of residence. With planning, in many states, students can combine a B.S. in Meteorology with education courses to receive a Master's degree in education and teaching certification in a five-year program. In some places, there are other opportunities to gain teaching credentials in intensive programs that allow employment in public and private schools without formal graduate training.

The standard atmospheric science degree provides a fundamental background in mathematics, physics, and chemistry, with applications to atmospheric science. If possible, students should also take introductory courses in geology, astronomy, and oceanography so as to prepare themselves for Earth-science teacher certification. Additional introductory coursework in biology and possibly chemistry would be appropriate for a general science teacher.

e. Other Career Options

The field of atmospheric science is changing rapidly, and the list of specializations above is not intended to be comprehensive. Many new career paths are interdisciplinary, applying the principles of meteorology and climatology to the environment and human behavior. Many specialties exist as employment niches or may expand into major future career paths. Examples of these fields include hydrometeorology, transportation support, instrumentation development, space weather, agricultural meteorology, and renewable energy planning and forecasting. The latter field, in particular, is enjoying rapid growth at present, as commercial wind and solar energy becomes more widely developed. Students considering specializing in renewable energy

would benefit from an introduction to the basic technology of wind and solar energy and detailed study of the planetary boundary layer and topographic influences on wind and weather.

**Appendix: Federal civil service requirements for meteorologist positions
(GS 1340, effective 1 March 1998)**

The basic requirements for federal employment as a meteorologist are given below:

A. A degree in meteorology, atmospheric science, or other natural science major that includes the following:

- 1) At least 24 semester hours (36 quarter hours) of credit in meteorology/atmospheric science, including a minimum of
 - a) 6 semester hours in atmospheric dynamics and thermodynamics;¹
 - b) 6 semester hours in analysis and prediction of weather systems (synoptic/mesoscale);
 - c) 3 semester hours of physical meteorology, and
 - d) 2 semester hours of remote sensing of the atmosphere and/or instrumentation;
- 2) 6 semester hours of physics, with at least one course that includes a laboratory session¹;
- 3) 3 semester hours of ordinary differential equations¹; and
- 4) at least 9 semester hours of course work for a physical science major in any combination of three or more of the following: physical hydrology, statistics, chemistry, physical oceanography, physical climatology, radiative transfer, aeronomy, advanced thermodynamics, advanced electricity and magnetism, light and optics, and computer science.

Or

B. A combination of education and experience – course work as shown in A above, plus appropriate experience or additional education.

¹ There is a prerequisite or corequisite of calculus for course work in atmospheric dynamics and thermodynamics, physics, and differential equations. Calculus courses must be appropriate for a physical science major.