Department of Atmospheric Sciences

Graduate Program Guide

2009-2010

Box 351640
UNIVERSITY OF WASHINGTON
Seattle, Washington
98195

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GRADUATE PROGRAM GUIDE

Professor Dale R. Durran, Chair

Professor Gregory J. Hakim, Graduate Program Coordinator

WEB: http://www.atmos.washington.edu
Advising Office
Room 416 ATG
(206) 543-4576

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TABLE OF CONTENTS

I. INTRODUCTION

Rapid growth of research in atmospheric sciences began in the late 1940s in response to needs and opportunities in weather forecasting. Thus, the Department of Atmospheric Sciences at the University of Washington was established in 1947. Today, intensive research is underway to extend the time scale over which useful forecasts can be made and to increase the amount of regional and temporal detail in short-range forecasts.

In addition, the atmospheric sciences now address a broad range of other problems of fundamental interest and importance. Examples include changes in climate that could result from increases in atmospheric carbon dioxide and other greenhouse gases, acid rain associated with industrial effluents, and the application of remote-sensing techniques to the monitoring and understanding of weather and climate.

Graduate students in the atmospheric sciences come from a variety of disciplines: physics, chemistry, engineering, atmospheric or geophysical sciences, and applied mathematics. Opportunities are broad enough that each of these backgrounds is valuable for specific fields within the atmospheric sciences. Students should nevertheless have in common a solid background in fundamental physics and applied mathematics. Research in the atmospheric sciences often extends beyond the strict limits of the subject into other areas of geophysical and environmental sciences. Depending upon their special interests, students may take courses in physics, mathematics, chemistry, oceanography, geophysics, engineering and other fields.

II. FACULTY MEMBERS

Academic Faculty

Thomas P. Ackerman, Ph.D. (University of Washington), Professor. Atmospheric Sciences and Director of Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington. Radiative transfer; remote sensing of cloud properties; effect of clouds and aerosol on the global climate.

Becky Alexander, Ph.D. (University of California, San Diego), Assistant Professor. Paleoclimate; atmospheric chemistry; aerosols; stable isotope geochemistry.

David S. Battisti, Ph.D. (University of Washington), Professor. Large-scale atmosphere-ocean dynamics; tropical circulation; physics of natural variability in Arctic climate; climate dynamics; paleoclimate.

Cecilia M. Bitz, Ph.D. (University of Washington), Associate Professor. High latitude climate dynamics; climate change; paleoclimate; climate modeling; sea ice modeling.

Christopher S. Bretherton, Ph.D. (Massachusetts Institute of Technology), Professor. Atmospheric Sciences and Applied Mathematics. Role of clouds in atmospheric convection and climate; boundary layer meteorology; numerical modeling; tropical meteorology.

Dale R. Durran, Ph.D. (Massachusetts Institute of Technology), Professor. Atmospheric dynamics; numerical methods and atmospheric modeling; mountain meteorology; mesoscale meteorology.

Dargan M. W. Frierson, Ph.D. (Princeton University), Assistant Professor. Atmospheric general circulation; water vapor; climate change.

Qiang Fu, Ph.D. (University of Utah), Professor. Atmospheric radiation; cloud/aerosol/radiation/climate interactions, remote sensing.

Gregory J. Hakim, Ph.D. (University at Albany, State University of New York), Associate Professor. Synoptic and mesoscale meteorology; atmospheric dynamics; data assimilation; turbulence.

Dennis L. Hartmann, Ph.D. (Princeton University), Professor. Climate change; dynamic meteorology; radiation and remote sensing.

Robert A. Houze, Ph.D. (Massachusetts Institute of Technology), Professor. Mesoscale meteorology; cloud physics and dynamics; radar meteorology; tropical and mountain meteorology.

Lyatt Jaeglé, Ph.D. (California Institute of Technology), Associate Professor. Atmospheric chemistry; tropospheric and stratospheric photochemistry; chemical modeling of atmospheric observations; influence of human activities on the composition of the atmosphere.

Clifford F. Mass, Ph.D. (University of Washington), Professor. Synoptic and mesoscale meteorology.

Peter B. Rhines, Ph.D. (Trinity College, University of Cambridge, United Kingdom), Professor. Oceanography and Atmospheric Sciences. Theoretical physical oceanography; geophysical fluid dynamics; general circulation of the atmosphere and ocean.

Joel Thornton, Ph.D. (University of California, Berkeley), Assistant Professor. In situ and laboratory studies of homogeneous and heterogeneous atmospheric chemical processes; air pollution; atmosphere-biosphere interactions.

John Michael Wallace, Ph.D. (Massachusetts Institute of Technology), Professor. Atmospheric general circulation; climate variability.

Stephen G. Warren, Ph.D. (Harvard University), Professor. Atmospheric Sciences and Earth & Space Sciences. Atmospheric radiation; radiative properties of clouds, snow, and sea ice; Antarctic climate; global cloud climatology.

Robert Wood, Ph.D. (University of Reading), Associate Professor. Boundary layer cloud structure, cloud microphysics, remote sensing.

Research Faculty

Theodore L. Anderson, Ph.D. (University of Washington), Research Associate Professor. Aerosols and climate; aerosol instrumentation; satellite remote sensing.

David S. Covert, Ph.D. (University of Washington), Research Professor. Atmospheric chemistry; aerosol physics, chemistry and optics; aerosol instrumentation; climate effects and global distributions of aerosols.

Thomas C. Grenfell, Ph.D. (University of Washington), Research Professor. Atmospheric radiation; radiative transfer; microwave remote sensing; sea ice and snow optics; microwave theory.

Dean A. Hegg, Ph.D. (University of Washington), Research Professor. Atmospheric chemistry; cloud physics.

Jérôme Patoux, Ph.D. (University of Washington), Research Assistant Professor. Planetary boundary layer modeling; air-sea interaction; satellite remote sensing; synoptic meteorology.

Bradley F. Smull, Ph.D. (University of Washington), Research Associate Professor. Mesoscale and radar meteorology; severe storms; tropical convection; large-scale atmosphere-ocean interactions, orographic precipitation processes.

Mark T. Stoelinga, Ph.D. (University of Washington), Research Assistant Professor. Mesoscale and synoptic meteorology; atmospheric dynamics; cloud physics.

Emeritus Faculty

Marcia B. Baker, Ph.D. (University of Washington), Professor Emeritus. Geophysics and Atmospheric Sciences. Cloud microphysics; electrification.

Robert A. Brown, Ph.D. (University of Washington), Research Professor Emeritus. Geophysical fluid dynamics; planetary boundary layers; air-sea interaction; turbulence; satellite remote sensing.

Joost A. Businger, Ph.D. (State University, Utrecht, the Netherlands), Professor Emeritus. Air-sea interaction; boundary layer meteorology; atmospheric turbulence.

Robert J. Charlson, Ph.D. (University of Washington), Professor Emeritus. Atmospheric Sciences and Chemistry. Atmospheric chemistry; aerosol physics; aerosol/cloud/climate interaction; aerosol and cloud instrumentation.

Robert G. Fleagle, Ph.D. (New York University), Professor Emeritus. Air-sea interaction; science policy.

Halstead Harrison, Ph.D. (Stanford University), Associate Professor Emeritus. Atmospheric chemistry; dispersion modeling; radiative transfer.

Conway B. Leovy, Ph.D. (Massachusetts Institute of Technology), Professor Emeritus, Atmospheric Sciences and Geophysics. Climatic role of clouds; planetary atmospheres and astrobiology; upper atmosphere circulation and dynamics.

Gary A. Maykut, Ph.D. (University of Washington), Research Professor Emeritus, Atmospheric Sciences and Geophysics. Polar air-sea-ice interaction; radiative transfer in ice and snow.

Edward S. Sarachik, Ph.D. (Brandeis University), Professor Emeritus. Atmospheric dynamics; large-scale atmosphere-ocean interactions; greenhouse warming; equatorial dynamics; El Niño/Southern Oscillation; climate change.

James E. Tillman, M.S. (Massachusetts Institute of Technology), Research Professor Emeritus. Mars meteorology: global oscillations, great dust storms and planetary boundary layer of Earth and Mars; humidity, temperature and wind instrumentation; K-12 and public outreach programs.

Norbert Untersteiner, Ph.D. (Innsbruck University, Austria), Professor Emeritus. Atmospheric Sciences and Geophysics. Sydney Chapman Professor of Physical Sciences, University of Alaska. Air-sea-ice interaction; polar climatology; sea ice physics.

III. FIELDS OF GRADUATE STUDY AND RESEARCH

The faculty, staff and students in the Department of Atmospheric Sciences at the University of Washington are engaged in the study of a broad range of atmospheric phenomena and processes, using methods ranging from mathematical analysis to field experimentation. Research projects range in size from small studies involving individual scientists to large national and international programs involving teams of scientists.

Research groups in the department are concerned with Atmospheric Chemistry, Atmospheric Dynamics, Boundary Layer Processes, Cloud and Aerosol Research, Glaciology and Planetary Atmospheres, Cloud Dynamics, Precipitation Processes, Storms, Weather Analysis and Forecasting, Climate, Global change, Airflow over mountains, and other topics. Some groups maintain special research facilities for the use of their students. In some of these activities, there is close cooperation with the nearby Pacific Marine Environmental Laboratories at the National Oceanic and Atmospheric Administration (NOAA) Regional Center through the Joint Institute for the Study of the Atmosphere and Ocean (JISAO). Faculty members often have interests in more than one area, and research projects frequently involve questions of broad scope which do not fall neatly into a single category. This is particularly true of research projects directed toward understanding the chemical and physical modification of the environment by human activities.

The major research groups within the Department are described below. A number of specific research topics currently under study are also highlighted.

Atmospheric Chemistry

The atmosphere is chemically complex and evolving due to natural events, biological and anthropogenic activities; it has fundamental chemical links to the oceans, the solid earth and the biota. Anthropogenic perturbations such as land-use and industrial activities have profoundly modified the chemical composition of the troposphere and stratosphere, with potentially important consequences on future climate and living organisms. Examples of such changes include the formation of an ozone hole over Antarctica since the late 1970s, the observed trends in long-lived greenhouse gases, the change in the concentrations of tropospheric ozone and acidic deposition due to growing emissions of hydrocarbons, nitrogen oxides and sulfur dioxide in industrialized regions.

Laboratory studies, in situ experiments and modeling activities by atmospheric chemists at the University of Washington are directed at determining chemical composition and chemical processes in the atmosphere and in turn their effects on the atmosphere, and on a larger scale the biogeochemistry of the earth. The laboratory and experimental research deals with trace gas measurements and physical, chemical and optical properties of particles. Global models of atmospheric chemistry and climate use these observations to improve their predictions of future changes in atmospheric composition, and also guide the development of analytical techniques and the logistics of large-scale field measurement programs.

Atmospheric Dynamics

Atmospheric dynamics involves observational and theoretical analysis of all motion systems of meteorological significance, including such diverse phenomena as thunderstorms, tornadoes, gravity waves, tropical hurricanes, extratropical cyclones, jet streams, and global-scale circulations. The immediate goal of dynamical studies is to explain the observed circulations on the basis of fundamental physical principles. The practical objectives of such studies include improving weather prediction, developing methods for prediction of short-term (seasonal and interannual) climate fluctuations, and understanding the implications of human-induced perturbations (e.g., increased carbon dioxide concentrations or depletion of the ozone layer) on the global climate.

The Department has active research programs studying problems on the global scale, the synoptic scale, and the mesoscale. Research on global-scale problems includes many topics related to climate change and climate variability, stratospheric dynamics, and the general circulation. Research on the synoptic scale focuses on the development of extratropical cyclones, the dynamical influence of the tropopause, rotating stratified turbulence, and data assimilation. On the mesoscale our efforts are concentrated on topographically induced flows, orographic precipitation, gravity waves and stratospheric-troposphere exchange through mixing at the top of deep cumulonimbus clouds. These problems are attacked with a combination of theory, numerical simulation and observational analysis.

Boundary Layer Research

The structure and dynamics of the lowest layer of the atmosphere which comprises the planetary boundary layer (PBL) are of vital importance for the understanding of weather and climate, the dispersion of pollutants, and the exchange of heat, water vapor and momentum with the underlying surface. Processes of special interest within the PBL include the vertical transfer of momentum, heat and water vapor by turbulence, and the absorption and emission of radiation at the surface and within the atmosphere. One focus of the Boundary Layer Research Group's efforts is on the development and testing of instrumentation for measuring the turbulent fluctuations of velocity components, temperature and humidity. Another focus is on the theoretical analysis and interpretation of turbulent statistics and flow dynamics. The importance of instabilities, secondary flows, and coherent structures has been an important part of this study. The area of air-sea interaction has been a primary area of research. Several large experiments have been conducted by the department. Present emphasis is on the role of the boundary layer in the growth and decay of cyclones and satellite capabilities in ocean measurements.

Faculty and students are engaged in a variety of field and theoretical projects including the study of surface fluxes, mesoscale variations in boundary layer structure, and effects of variable terrain and variable seastate. Observations have been made from fixed towers, floating buoys, ships, tethered balloons, aircraft and satellites. Data from satellite instruments such as scatterometers and multichannel scanning microwave radiometers are being used to infer the global structure of the marine planetary boundary layer. Field studies are made jointly with teams from other universities and research institutes. Departmental researchers have participated in many international research programs in many parts of the globe, from the tropics to the Arctic.

Climate Fluctuations and Change

As human activity continues to alter atmospheric composition and begins to change climate on a global scale, the challenge of understanding the global system comprised of the atmosphere, oceans, ice and vegetation takes on a heightened sense of urgency. Climate research is also motivated by substantial economic benefits from improved weather and climate prediction on time scales ranging from weeks to seasons or longer.

Faculty and students in the department are engaged in a number of projects directed toward a better understanding of climate variability and long-term climate change, including: dynamics of atmospheric variability on time scales of weeks or longer and its relation to extreme events such as droughts and unseasonable warmth or cold; the El Nino phenomenon in the equatorial Pacific and its effects on global climate; decadal and century variability in the mid-latitude and polar regions; the predictability of El Nino and other natural climate phenomenon; long term variability of the deep ocean circulations driven by gradients of heat and salt and their role in the uptake of heat and carbon; the role of clouds, aerosols, sea-ice and land vegetation in determining the sensitivity of the climate system; the problem of distinguishing between natural climate variability and climate change induced by human activity; and climates of the past including ice ages and equable warm climates. The research involves the analysis of global data sets of all kinds, including in situ data, remotely sensed data, and data that have been assimilated into a model in order to produce a consistent global analysis; testing and improvement of global climate system models; and experiments with an array of numerical models of the various components of the climate system.

Cloud and Aerosol Research

Cloud and Aerosol Research is concerned with three broad areas of research that overlap in many important ways: atmospheric aerosols and trace gases, the physics and chemistry of clouds and precipitation, and mesoscale processes associated with cloud and precipitation systems.

The atmospheric aerosol and trace gas studies are concerned with the origins of various particles and gases in the air and their effects on the atmosphere on local, regional and global scales. This has involved the group in airborne measurements in many locations around the world and in studies of the emissions of particles and gases from the ocean, volcanos, forest fires and industries. Recent field projects have been carried out in Brazil, the Arctic, the Marshal Islands, Southern Africa , as well as North America.

For many years the department has been engaged in studies of the structures of clouds and the various processes that can lead to precipitation. Although rooted in field observations, this work includes conceptual and numerical model development. Current studies include the effects of clouds on the radiative balance of the earth and climate as well as mesoscale studies of cloud and precipitation systems. One of the unique aspects of these studies is the blending of synoptic, mesoscale and microscale analyses. These studies have led to new conceptual models for the structures of winter cyclones on the west coast, east coast and central United States. Current projects include the analysis of a large data set on the structure of clouds in the pacific Northwest with the goal of improving the representation of cloud and precipitation processes in mesoscale models (The IMPROVE Project).

Cloud Dynamics, Precipitation Processes and Storms

These studies are concerned with the organization of air motions and precipitation processes in all types of clouds, ranging from oceanic stratus clouds to tropical convection to fronts passing over mountain ranges. This area of research emphasizes the analysis of observations of storms by aircraft, radar and satellite and interpretation of the data via numerical modeling of the clouds. These studies aim to help understand the role of clouds and precipitation in the global atmospheric circulation and climate and to improve the forecasting of precipitation and severe weather.

Students and faculty often participate in field experiments to study precipitating cloud systems in various locations around the world. Recent projects in midlatitudes focus on the physics and dynamics of rainfall over the European Alps and the Oregon Cascades. Current work on tropical precipitation includes analysis of observations with satellite-borne radars and microwave sensors on the TRMM satellite. Ground based observations at Kwajalein Atoll in the Marshall Islands are being used to validate and understand the satellite observations. Shipborne radar is being used to study precipitation in the Indian Monsoon and the Intertropical Convergence Zone. A project is planned to used aircraft radar data to study rainband/eyewall interactions in hurricanes.

Glaciology

The glaciological research in the Department is aimed at understanding local and small-scale processes related to snow and ice and predicting their role in regional and global climate. The structural and optical properties of snow, sea ice, and pure ice and their interaction with radiation across the solar spectrum and the thermal infrared are being studied in cold-room laboratories and field projects carried out in both the Arctic and Antarctic. Microwave properties of sea ice are being investigated experimentally and theoretically for application to satellite remote sensing. The heat and mass exchanges involved in the growth and decay of sea ice, and air/sea interaction in the presence of an ice cover, are studied by experiments in the Arctic Ocean and by computer modeling. The wind-driven circulation of sea ice is studied using drifting buoys. Changes in the statistical distribution and overall thickness of Arctic sea ice are being investigated using upward-looking submarine sonar observations. Researchers from the Department have been conducting multiplidisciplinary fieldwork in the Arctic Ocean and adjacent seas since 1957.

Students in the Department are part of the large and active glaciological community at the University, which includes members in the Department of Earth and Space Sciences (glacier dynamics), the Quaternary Research Center (glacial geology, permafrost, isotope chemistry of polar ice cores), and the Oceanography Department (polar oceanography). The Polar Science Center, a branch of the Applied Physics Laboratory, is dedicated to research in high-latitude oceanography, sea ice processes, air-sea-ice interaction, and remote sensing of ice and snow, and climate change.

Mesoscale Meteorology

Mesoscale meteorology is the study of atmospheric phenomena with typical spatial scales between 10 and 1000 km. Examples of mesoscale phenomena include thunderstorms, gap winds, downslope windstorms, land-sea breezes, and squall lines. Many of the weather phenomena that most directly impact human activity occur on the mesoscale. Research in mesoscale meteorology has been spurred by recent advances in observational and numerical modeling capabilities that have greatly improved the tools used by atmospheric scientists to study mesoscale weather systems.

Faculty and students in the department are actively involved in a large number of different research projects in mesoscale meteorology. These include studies of convective cloud clusters and squall lines in the tropics and mid-latitudes, studies of precipitation bands along fronts, the investigation of marine stratus and strato-cumulus over the sub-tropical oceans, and research on topographically forced flows such as downslope windstorms, the blocking and channeling of the winds by orography, mountain-wave induced rotors, and the prediction of precipitation in complex terrain. These phenomena are studied using in situ observations, remote sensing, and both idealized and highly realistic mathematical models. Many local weather phenomena of the Pacific Northwest are also under study in the department, where a very high resolution weather forecast model for the Puget Sound region is run twice daily on an operational basis.

Middle Atmosphere Meteorology

The middle atmosphere (stratosphere and mesosphere) is the region of the atmosphere between about 12 and 80 km altitude. Studies of dynamical and chemical processes in this region have greatly expanded in recent years owing to the impact of human activities on the stratospheric ozone layer, and the coupling between stratospheric changes and surface climate. The University of Washington has a distinguished record of research on the meteorology of the middle atmosphere. Research efforts are divided between analysis of observational data and theoretical studies based on numerical models. A primary area of emphasis is study of the dynamical interactions between the troposphere and the stratosphere, including the transfer of momentum and trace constituents across the tropopause. This effort requires understanding of the influence of both large- and small-scale wave motions on the momentum balance and mass circulation of the middle atmosphere. Members of the department are active in analysis and interpretation of middle atmosphere data from NASA research satellites. Students and faculty also employ a variety of models, ranging from global scale circulation models to mesoscale convective storm models, to study the links between the troposphere and the stratosphere.

Planetary Atmospheres

The behavior of the atmospheres of other planets is of interest in its own right and may provide insights of value in the study of our own atmosphere and climate system. Efforts are focused primarily on Mars. We use computer models and data from recent spacecraft (such as NASA's

Mars Global Surveyor) to improve our understanding of the atmospheric dynamics and climate system of Mars. A small effort is also devoted to developing instrumentation for future space missions to measure Martian weather and climate.

The evolution of planetary atmospheres is a further area of research. Here the goal is to understand the nature of past atmospheres from the signatures they have left behind. These signatures can be physical or chemical. For example, on Mars such signatures arise from the effects of wind erosion of the planet's surface, chemical interaction of the atmosphere with the surface, and atmospheric loss to space. The chemica evolution of the Earth's atmosphere is also studied within such a broad, planetary context. The Earth's atmosphere is chemically coupled to the biosphere because all the important atmospheric gases, with the sole exception of argon, are biologically mediated to some extent. Computer models that incorporate climate and biogeochemical feedbacks are being developed to understand the past evolution of Earth's atmosphere. This effort is part of the cross-campus Astrobiology (AB) Program and benefits from the expertise of AB Program faculty, which covers a wide variety of relevant disciplines from astronomy to oceanography to microbiology.

Radiative Transfer and Remote Sensing

The rapid growth in atmospheric radiation studies in recent years is a result both of the increasing use of satellites to monitor atmospheric phenomena and of the increased emphasis on climate modeling. Because satellites measure only radiation, the interpretation of their data requires the study of radiative transfer in the atmosphere. Because the transfer of solar and terrestrial radiation represents the prime physical process that drives the circulation of the atmosphere and the ocean, an understanding of climate and the mechanisms of climatic changes also requires detailed understanding of radiative processes and the radiative energy balance in the earth-atmosphere system.

Current and recent research projects include the use of satellite data for microwave remote sensing of sea-surface temperatures, winds, humidity and liquid and ice water content of clouds, infrared remote sensing of upper atmosphere composition and dynamics, evaluation of the influence of clouds on the regional and interannual variations of the earth's radiation budget, and investigation of cloud-radiation interactions and their feedback to the climate system. Surface and aircraft fieldwork includes studies of solar and infrared radiation over the sea surface, microwave properties of sea ice, and light-absorption properties of atmospheric aerosols as well as the evaluations of GCM cloud and radiation parameterizations using ground-based remote sensing and in-situ aircraft observations. Theoretical work is underway to understand the light scattering by nonspherical ice particles and aerosols, to explain the radiative properties of snow and sea ice surfaces, to examine radiative processes in the upper atmosphere, and to study the influence of radiation on the maintenance of stratus clouds.

Synoptic Meteorology

Synoptic meteorology has traditionally been concerned with the analysis and prediction of large-scale weather systems, such as extratropical cyclones and their associated fronts and jet streams. An important aim of synoptic training is to acquaint the student with the structure and behavior of the real atmosphere. This is accomplished formally through coursework and informally through the maintenance of a facility for display of weather information including station reports, satellite pictures and a wide variety of weather maps and prognostic charts. An expanding interactive computer system allows convenient display and manipulation of meteorological data. The department maintains an extensive archive of weather maps, satellite imagery and station reports.

Recent synoptic research in the Department has dealt with such diverse subjects as the large-scale tropical and subtropical disturbances, extratropical cyclones, polar lows, the interactions between tropical and extratropical systems, and the large-scale effects of volcanic eruptions. Modeling and observational analyses are combined in an integrated approach to synoptic meteorology.

IV. RESEARCH ASSISTANTSHIP AND APPLICATION INFORMATION

Admission as a graduate student in Atmospheric Sciences is competitive. A minimum undergraduate grade-point average of 3.0 (B average) is required. The Department requires that all applicants take the Aptitude Test portion of the Graduate Record Examination. Information concerning the GRE may be obtained by going to: http://www.gre.org .

The Application for Graduate Admission should be completed online at: http://www.grad.washington.edu/admissions. There is also and application fee which should be paid online. Online application includes Statement of Interests, current resume, and designation of three (3) letters of recommendation.

All other materials for admission to the Atmospheric Sciences program should be sent directly to the Department. The materials are:

•The Graduate Record Examination (GRE) scores,
•An official copy of the transcripts,
•A printed, signed copy of the graduate application for admission,

Applications for admission to the Autumn Quarter (the only quarter for which students are admitted) must be made prior to 15 January.

Students whose native language is not English must take the Test of English as a Second Language (TOEFL). Successful applicants with a score of less than 580 will be required to take an English as a Second Language course during their first quarter of residence. Please note that before a student can be admitted we must have the original copy of both the GRE and TOEFL scores.

Stipends for beginning Research Assistants for the 2009-2010 year are approximately $1,799 per month during the academic year, and approximately twice that amount per month for 2.5 summer months, for an annual total of $25,186. The stipend increases as a student advances through the program, to a current maximum of $27,678 per annum for students who have passed the General Examination. Out-of-state tuition is waived and in-state tuition is paid for Research Assistants, as is medical, visual and dental insurance. Students are expected to work half-time, 20 hours per week, on research during the academic year, and fulltime during the summer.

Graduate students are required to serve as Teaching Assistants for one or two quarters. The first quarter in which a student serves as a TA usually occurs during their second graduate year. The TA stipend will be at the same rate as the student's research assistantship.

V. INITIAL PROGRAM OF STUDY

The Department of Atmospheric Sciences offers programs of graduate study leading to the degrees of Master of Sciences (M.S.) and Doctor of Philosophy (Ph.D.). The Department also cooperates in offering studies leading to degrees of M.S. and Ph.D. under the interdepartmental Program on Climate Change and Program on Astrobiology and under less formal arrangements with other degree-granting units on campus.

While the graduate program has no specific prerequisites, it is generally recommended that at least two years of mathematics (beginning with calculus and going through differential equations) be taken prior to applying for admission into the program, as well as one and one half years of calculus based physics. Other courses in mathematics, computer science and the various physical sciences would also be appropriate, depending upon a student's interest in a specific aspect of the atmospheric sciences. (A student interested in atmospheric chemistry might, for example, take additional courses in chemistry).

After admission into the program, each student must confer with the Graduate Program Coordinator prior to registration for the first quarter. Full-time students normally register for 18 credits (including research and seminar credits) in each quarter of the first year.

For most students, the first year of graduate study is devoted largely to basic courses in atmospheric sciences and mathematical methods. Research projects and graduate courses in the Department of Atmospheric Sciences are closely related, and the well-prepared graduate student may expect to begin research work rather quickly. Virtually all advanced students devote at least half-time to research that may include experimental laboratory work, observations in the field, data analysis, numerical simulation, and mathematical analysis.

Graduate students entering the Department of Atmospheric Sciences will be assigned a primary faculty advisor. A supervisory committee will be established with the primary faculty advisor as chairman, by the end of the first year in residence.

End of First Summer Seminar

Faculty advisors are expected to meet frequently with their first-year students during the summer to help them begin their thesis research, and, for masters students, to establish a focused plan for the master's thesis. All first-year students are required to give a 20-minute presentation in a one-day seminar at the end of the summer quarter of their first year of study. The presentation should describe their progress toward defining a thesis topic and on articulating the goals and proposed methodology that will be used to carry out their research. Preliminary results, if available, can also be presented, but students are not expected to have actually obtained significant results at this early stage of their studies. This seminar usually takes place the week before Fall-quarter classes begin. To keep the presentations casual and low-key, only professors, the class of incoming graduate students and the presenters are invited to attend the seminars.

VI. THE DEGREE OF MASTER OF SCIENCE

Objective: *The program leading to the degree of Master of Sciences is intended to enable the student to grow with his field throughout his scientific career, to recognize and understand new concepts, and to master new procedures as they emerge in the literature.*

Achievement of this objective requires that the student understand the fundamental principles of physics that are relevant to the atmosphere, acquire a thorough and comprehensive knowledge of atmospheric properties and behavior, and develop critical facilities.

M.S. Requirements

1. A minimum of 36 quarter credits (27 graded course credits and a minimum of 9 credits of thesis) must be presented, of which at least 3 credits must be in approved applied mathematics courses and 24 must be in atmospheric sciences courses numbered above 500 (exclusive of seminars, colloquia or research credits).

2. The Graduate School accepts numerical grades in (a) approved 400-level courses accepted as part of the major, and (b) in all 500-level courses. A minimum cumulative gradepoint average of 3.0 is required for a graduate degree at the University. A minimum grade of 2.7 must be earned in each course presented to satisfy the required 24 credits of atmospheric sciences courses numbered above 500 (exclusive of research or thesis) and the 3 credits in applied mathematics.

3. By the end of the third week of the fall quarter of each Master's student's second academic year, the student and the faculty advisor must submit a coauthored thesis plan to the student's thesis committee. An informational copy will also be filed with the departmental office. The plan should be only a few pages long; it should concisely present the questions to be addressed and the methodology that will be used in the thesis research. The plan should include a nominal timetable, indicating milestones against which the next year's progress can be measured. This plan must be approved by the student's thesis committee by the end of the fifth week of autumn quarter. There are no automatic penalties for deviations from this plan or failure to meet the estimates in the timetable. The thesis plan simply provides a well-defined launching point for the remainder of the thesis research.

4. The M.S. thesis should be directed toward the solution of a problem of substantial scientific importance and should demonstrate the student's ability to use research methods in a limited area and to discuss critically the student's own and other investigators' work. The student must submit a graduation application via the Graduate School's website by the end of the 8th week of the quarter (6th week in summer quarter). The thesis must be prepared in accordance with the rules and procedures of the Graduate School, and must be approved by the Supervisory Committee, presented orally to the faculty and students, and defended in discussion. In addition to the two copies of each thesis that must be submitted to the Graduate School, one copy must be filed with the Chairman of the Supervisory Committee and one with the Department.

VII. PROCEDURES FOR PH.D. QUALIFICATION

All students admitted into the Atmospheric Sciences graduate program will be admitted initially to the M.S. track of study.

A student who wishes to be considered by COGS must first write a letter to the Academic Counselor, Samantha Scherer, and also to his/her M.S. committee, requesting admission into the Ph.D. program, and choosing one of the three following evaluation options:

(1) A student entering the department, having already earned an M.S. degree in Atmospheric Sciences or a closely related discipline, may submit his/her thesis for evaluation by COGS (Committee on Graduate Studies) by the end of the last week prior to the autumn quarter of his/her second academic year in the department.

(2) A student may submit a draft of his/her University of Washington Department of Atmospheric Sciences M.S. for evaluation by the COGS. This draft must have been read and approved by his/her M.S. supervisory committee prior to submission.

(3) A student may submit, for evaluation by the COGS, the manuscript of a journal article on which the student is lead author. The manuscript must have been submitted to a refereed journal prior to submission to the COGS.

Course Requirement

A student who wishes to enter the Ph.D. program through options (2) and (3) must finish the required graduate courses listed on page 19 prior to evaluation by COGS.

Students who have already taken equivalents of some of the required graduate courses may petition COGS to skip these courses. This may require an oral examination by a COGS-selected faculty member to test the student's proficiency in the required course material and/or documentation of the contents and student performance in the previously taken courses. For a student through the options (2) and (3), such petitions must be approved by the COGS at least one year before the COGS evaluates the student's entry into the Ph.D. program.

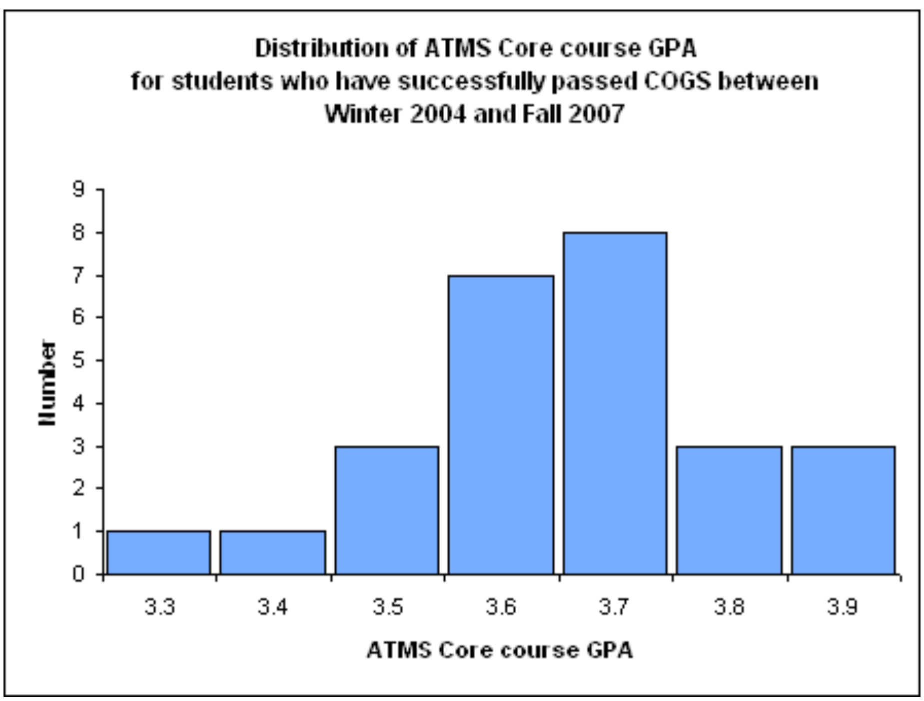
Seminar Requirement

Regardless of the basis for evaluation, the student will be expected to give a public defense of his/her research prior to evaluation by COGS. Written comments concerning the student's qualifications will be solicited from departmental faculty in advance of the evaluation. The seminar should be given during the first five weeks of the quarter of submission to COGS, on a date chosen in coordination with COGS and the student’s M.S. committee. The student will give an oral presentation (of 30-40 minutes) and answer questions in a public defense open to all faculty and students. Immediately after the public defense, members of the student’s M.S. committee and of COGS will meet with the student for more detailed questions. The chair of

COGS will lead this closed-door part of the defense. At least 2 members of COGS and 2 members of the student's M.S. committee must be present.

Evaluation by the COGS

Evaluation by the COGS will take into account the student's research potential and academic record. The evaluation of the academic record will be based mainly on the level of difficulty and breadth of the courses taken and the grades earned in those courses, with particular emphasis on the required atmospheric sciences core courses. The COGS has no set threshold for a minimum GPA in core ATMS courses, but students can consult the distribution of GPAs of students who have successfully passed COGS. The research potential will be evaluated from the M.S. thesis or any manuscript submitted. In addition, for options (2) and (3), COGS will be strongly influenced by the M.S. supervisory committee's written evaluation of the thesis or manuscript, and the committee's recommendation as to whether it constitutes sufficient evidence of research capability to qualify the student for the PhD program. This recommendation letter should describe in detail the ideas in the thesis or paper that came from the student. The letter should also give examples that demonstrate creativity, independent thought, initiative, and critical thinking in the student's work. The COGS will also take into account the elapsed time during which the research was carried out. The COGS may solicit comments concerning the student's academic or research performance from individual departmental faculty members. In the event of a negative decision, the COGS will consider one subsequent request for reevaluation provided that second request is made before exceeding the time limitation described below.



Time Limitation

A student may be considered for acceptance into the departmental PhD program for up to three years from the time of entry into the Atmospheric Sciences graduate program, not including academic quarters in which the student is (a) on leave from the university, (b) predominantly occupied with field (or other research projects) that are not directly thesis related, or (c) predominantly devoted to satisfying course requirements for extradepartmental academic programs in which the student is registered. It is expected that most students will serve for one or two quarters as a teaching assistant during this three-year period. Quarters not counted toward the three-year limit are subject to the approval by the COGS and in the case of (b) and (c) COGS approval must be requested during the academic quarter(s) in question. For a student entering the department during the autumn quarter and not granted any extensions, the formal deadline for submission of materials for evaluation by COGS will be the Friday before the beginning of the Autumn quarter of the student's fourth year in residence. Thus, the public seminar should be given no later than the fifth week of fall quarter of their fourth year.

The COGS will usually meet during the 6th or 7th week of each quarter. To allow for the COGS to thoroughly evaluate each application, all materials from the student and supervisory committee should be submitted to the COGS by the Friday before the beginning of the quarter. The student should notify Samantha Scherer of his/her intention to be considered by COGS at least one month before the beginning of the quarter. This will allow scheduling of the seminar during the first 5 weeks of the quarter.

Students who have completed an M.S. thesis but are still awaiting a COGS decision should continue to register for ATM S 700 research credits. They are allowed to do this for one quarter after the M.S. has been granted.

COGS Guidelines

Final decisions concerning admission to PhD candidacy will be delegated to the COGS, without the requirement for ratification by a vote of the entire departmental faculty; however, COGS decisions may be overruled by a 2/3 vote of the entire department faculty if there is an appeal by the student or his/her advisor.

The COGS is composed of five faculty members (with a quorum of four for meetings). COGS members will be excused from the COGS evaluation of students that they supervise. Academic faculty members chosen from a ranked list may be asked to substitute for regular COGS members if this is necessary to achieve a quorum for a timely COGS meeting. The terms of the members are three years and are staggered, so that there is memory from one year to the next. When the three-year term of the COGS chair is completed, one of the existing COGS members (after already serving on COGS for 1-3 years) will be appointed to a three-year term as new chair.

Qualification procedures prior to Autumn 2008

Students who entered the department prior to Autumn 2008 may be considered by COGS under the "old" rules that prevailed prior to April 2008. For information on the old procedures, go to the Atmospheric Sciences website or see the Student Services Coordinator. All students who wish to be considered by COGS under the old rules must submit their application materials to the Student Services Coordinator, Samantha Scherer, by the end of the first week of the quarter of submission.

VIII. THE DEGREE OF DOCTOR OF PHILOSOPHY

Objective: *The degree of Doctor of Philosophy signifies understanding of the nature of knowledge normally attained only through the original solution of a problem of substantial scientific importance.*

Requirements

A student must qualify for study toward the PhD by presenting an exceptional master's thesis or by presenting a seminar after submitting an article for publication by a refereed journal, and then by being nominated to COGS by the M.S. supervisory committee and then approved by COGS for admission into the Ph.D. program. A Ph.D. student must normally be accepted as a research student by a member of the faculty of the Department. Immediately upon qualifying for PhD study, the student will set up a Supervisory Committee of not less than five members. The student and the Supervisory Committee will jointly plan the remainder of his/her academic program. The Supervisory Committee will normally meet with the student at least annually.

Students are required to take supporting courses outside their areas of specialization. At least 6 credits must be earned in approved courses in mathematics or the physical sciences other than Atmospheric Sciences. An additional 36 graded credits in Atmospheric Science courses numbered above 500 (excluding seminars and colloquia) must be earned before the Final Examination. Courses at the 500 level in science or mathematics may be substituted, subject to the approval of the supervisory committee, for some of these additional units.

A total of 27 credits of the required Atmospheric Sciences and out-of-department course work should be completed in the student's first year. The remaining credits should be earned during the second and third years of residence by taking courses at a nominal rate of one class per quarter.

A minimum grade of 2.7 must be presented for each course used to satisfy the above requirements. A cumulative gpa of at least 3.00 is required for a graduate degree.

General Examination

The General Examination will either be taken no later than one year after admission into the Ph.D. program, or will conform to a timetable established by the COGS. The student must apply to take the exam at least three weeks in advance, by submitting an application to the Academic Counselor. The application must have the signatures of all members of the supervisory committee. The exam will consist of a substantial thesis proposal which includes a review of the pertinent literature, preliminary results on the subject of the student's research, and proposed future research and methodology.

In the event a student does not pass the General Examination, it may be retaken once, by the end of the second quarter after the first exam.

The General Examination itself normally consists of an oral examination that tests the student's understanding of an area of specialization (e.g., synoptic or dynamic meteorology, cloud physics, energy transfer, etc.) with emphasis on the subject of the student's intended thesis. Students who pass the General Examination are admitted as candidates for the Ph.D. degree.

Following the General Examination, the student normally continues research and thesis work. The student may, however, pursue such advanced course work directed toward an area of specialization as may be recommended by the Supervisory Committee. Neither grades earned in courses nor total credits are sufficient evidence of eligibility for the Ph.D. degree; they may, however, be used as guides in planning a program and as indicators of minimum standards.

Dissertation Defense

The dissertation is an important part of the candidate's program; it must represent an original contribution toward understanding a problem of substantial scientific importance. The dissertation must be prepared in accordance with the rules and procedures of the Graduate School. A Reading Committee consisting of three members of the supervisory committee will be appointed. The dissertation must be approved by this Committee, and it must be presented orally and defended at a Department of Atmospheric Sciences colloquium. The student must submit an application for graduation through the Academic Counselor no later than three weeks prior to the defense of the dissertation. In addition to the two copies that must be submitted to the Graduate School, one copy of the dissertation must be filed with the Department and one copy presented to the Supervisory Committee chairperson. The Final Examination is conducted following the oral presentation of the dissertation and is limited to the subject of the dissertation.

IX. REQUIRED COURSEWORK

The required classes for all entering graduate students are:

ATM S 501 (5) Fundamentals of Physical Meteorology.
ATM S 502 (3) Introduction to Synoptic Meteorology.
ATM S 535 (3) Cloud Physics
ATM S 532 (3) Radiation (Introductory)
ATM S 558 (3) Atmospheric Chemistry (Introductory)

and either of the following sequences

ATM S 505 (4) Introduction to Fluid Dynamics.
ATM S 509 (4) Geophysical Fluid Dynamics
ATM S 542 (3) Dynamic Meteorology of Mid-Latitude Weather Systems

or

ATM S 503 (3) Atmospheric Motions I
ATM S 504 (5) Atmospheric Motions II

Each quarter, in addition to required coursework or electives, students should enroll in colloquium, one seminar and up to 10 credits in ATM S 600, 700, or 800, not to exceed 18 maximum credits.

The two-course dynamics sequence is intended for those whose research specialty will be well outside the realm of dynamic meteorology. Most students are encouraged to take the three-course sequence in dynamics. Please see the Graduate Program Coordinator before enrolling in ATM S 503. The total units for these required courses is 25 or 28.

Ph.D students are required to take a minimum of 36 units of ATM S classes 500 or higher (excluding seminars and colloquia), as well as 6 credits of related coursework outside the department. (Note that for PCC students the series of 9 credits is easily accommodated).

Master's students need 27 units of course credit to graduate (excluding seminars and colloquia), with 24 of those units in Atmospheric Sciences. However, those students intending to pursue a Ph.D should take all of the courses required above.

FIRST YEAR STUDIES

AUTUMN:

ATM S 501 (5) Fundamentals of Physical Meteorology.
ATM S 505 (4) Introduction to Fluid Dynamics.
(ATM S 503 may replace 505 in some cases)

*Also select one of:
AMATH 567 (5) Analysis in Engineering I
AMATH 401 (4) Analytical Methods in Engineering I

Also select:
ATM S 520 (1) Atmospheric Sciences Colloquium
ATM S Seminar in area of interest (1)
ATM S 600 up to 10 credits, for a total of exactly 18 credits.

WINTER:

ATM S 509 (4) Geophysical Fluid Dynamics I
(ATM S 504 may replace 509 in some cases)
ATM S 532 (3) Radiation (Introductory)

*Also select one of:
AMATH 402 (4) Analytical Methods in Eng. II
AMATH 568 (5) Analysis in Eng. II

And:
ATM S 520 (1) Atmospheric Sciences Colloquium
ATM S Seminar in area of interest (1)
ATM S 600, up to 10 credits, for a total of exactly 18 credits.

SPRING:

<u>For those who took 503-504:</u>
ATM S 535 (3) Cloud Physics
ATM S 558 (3) Atmospheric Chemistry (Introductory)
Elective (3)

<u>For those who took 505-509:</u>
ATM S 542 (3) Dynamic Meteorology of Mid-Latitude Weather Systems
And two of:
ATM S 535 (3) Cloud Physics
ATM S 558 (3) Atmospheric Chemistry (Introductory)
Elective (3)
(Spring quarter continues)

Also select:

ATM S 520 (1) Atmospheric Sciences Colloquium
ATM S Seminar in area of interest (1)
ATM S 600 up to 10 credits, for a total of 18 credits.

*If the student already has the equivalent of a year of graduate level applied mathematics, then an elective may be taken for the third required course, after consultation with the Graduate Program Coordinator.

SECOND YEAR STUDIES

AUTUMN:
ATM S 502 (3)
ATM S 700 (10) Research Credits
ATM S 520 (1) Atmospheric Sciences Colloquium
Seminar (1)

WINTER:
Elective (3)
ATM S 700 (10) Research credits
ATM S 520 (1)
Seminar (1)

SPRING:
Select one of:
ATM S 535 (3)
ATM S 558 (3)
Elective (3)

And:
ATM S 700 (10) Research credits
ATM S 520 (1)
Seminar (1)

Note: Those interested in numerical modeling should take ATM S 581/AMATH 586 (Numerical Analysis for Time Dependent Problems) as an elective in the spring of their first year and take either 535 or 558 in the spring quarter of the second year.

XI. DESCRIPTION OF COURSES IN ATMOSPHERIC SCIENCES

Undergraduate Courses Which May Count Toward Graduate Work

431 ATMOSPHERIC PHYSICS (5) (A)
Energy transfer processes: solar and atmospheric radiation, turbulence and boundary layer structure, applications.
Prerequisites: 340 or PHYS 224.

451W INSTRUMENTS AND OBSERVATIONS (5) Sp
Principles of operating instruments for measuring important atmospheric parameters (e.g., temperature, humidity, aerosol concentration). Concepts of sensitivity, accuracy, representativeness, time response. Manipulation of output data including signal processing, and statistical analysis. Experimental design and implementation of the design in actual field experiments is included.
Prerequisites: STAT 311.

452 FORECASTING LABORATORY (5) Sp
Basic forecasting techniques. Application of numerical modeling and statistical approaches. Structure, evolution, and forecasting of convective systems. Radar applications. Diurnal and topographically-forced circulations. Aviation meteorology. Laboratories include extensive practice in forecasting and surface map analysis.
Prerequisites: 370 and 442.

458 GLOBAL ATMOSPHERIC CHEMISTRY (4) A
Global atmosphere as a chemical system; Physical factors and chemical processes. Natural variabilities and anthropogenic change. Cycling of trace substances. Global issues such as climate change, acidic deposition, influences on biosphere. Offered jointly with CHEM 458.
Prerequisite: either ATM S 358 or CHEM 456.

480 AIR QUALITY MODELING (3) W
Evaluation of air quality models relating air pollution emissions to environmental concentrations. Topics include meteorological dispersion models and various "receptor" models based on chemical "fingerprinting" of sources. Emphasizes current problems. Offered jointly with CIVE 480.
Prerequisite: 458/CHEM 458 or CIVE 490 or permission of instructor.

503 ATMOSPHERIC MOTIONS I (3) A
The basic equations governing atmospheric motions and their elementary applications; circulation and vorticity; basic dynamics of midlatitude disturbances.
Prerequisite: AMATH 353 or MATH 309; MATH 324.

504 ATMOSPHERIC MOTIONS II (5) W
Wave dynamics, numerical prediction, the development of midlatitude synoptic systems, and the general circulation.
Prerequisite: ATM S 441/503.

Courses for Graduates Only

501 FUNDAMENTALS OF PHYSICS AND CHEMISTRY OF THE ATMOSPHERE (5) A
Fundamentals of hydrostatics, thermodynamics, radiation, cloud physics and atmospheric chemistry.

502 INTRODUCTION TO SYNOPTIC METEOROLOGY (3) A

Overview of weather systems; atmospheric observations and data assimilation. Elementary manual and computer aided synoptic analysis techniques. Interpretation of satellite and ground based observations. Kinematics. Fronts and frontogenesis; life cycles of extratropical cyclones; related mesoscale phenomena. Numerical weather prediction; interpretation of forecast products.

505 INTRODUCTION TO FLUID DYNAMICS (4) A
Eulerian equations for mass, motion; Navier-Stokes equation for viscous fluids, Cartesion tensors, stress, strain relations; Kelvin's theorem, vortex dynamics; potential flows, flows with high, low Reynolds numbers; boundary layers, introduction to singular perturbation techniques; water waves; linear instability theory. Offered jointly with AMATH 505, OCEAN 511.
Prerequisites: AMATH 403 or permission of instructor.

508 GEOCHEMICAL CYCLES (4) Sp
Descriptive, quantitative aspects of earth as biogeochemical system. Study of equilibria, transport processes, chemical kinetics, biological processes; their application to carbon, sulfur, nitrogen, phosphorus, other elemental cycles. Stability of biogeochemical systems; nature of human perturbations of their dynamics. Offered jointly with CHEM 523, OCEAN 523.
Prerequisites: permission of instructor.

509 GEOPHYSICAL FLUID DYNAMICS I (4) W
Dynamics of rotating stratified fluid flow in the atmosphere/ocean and laboratory analogues. Equations of state, compressibility, Boussinesq approximation. Geostrophic balance, Rossby number. Poincare, Kelvin, Rossby waves, geostrophic adjustment. Ekman layers. Continuously stratified dynamics: Inertia gravity waves, potential vorticity, quasigeostrophy. Offered jointly with OCEAN 512.
Prerequisite: ATM S/AMATH 505/OCEAN 511.

510 PHYSICS OF ICE (3) W
Structure of the water molecule. Crystallographic structures of ice. Electrical, optical, thermal and mechanical properties of ice. Growth of ice from the vapor and liquid phases. Physical properties of snow. Offered jointly with ESS 531. (Offered alternate years).

511 FORMATION OF SNOW AND ICE MASSES (3) A
Snow and ice climatology. Formation of ice crystals in clouds. Snow metamorphism. Transfer of radiative, sensible, and latent heat at snow and ice surfaces. Remote sensing of snow and ice. Growth and melt of sea ice. Climatic records from ice. Offered jointly with ESS 532. (Offered alternate years). Prerequisite: Permission of instructor.

512 DYNAMICS OF SNOW AND ICE MASSES (3) Sp
Rheology of snow and ice. Sliding and processes at glacier beds. Thermal regime and motion of seasonal snow, glaciers, and ice sheets. Avalanches and glacier surges. Deformation and drift of sea ice. Response of natural ice masses to change in climate. Offered jointly with ESS 533. Offered alternate years.
Prerequisite: Permission of instructor.

513 STRUCTURAL GLACIOLOGY (3) W
Physical and chemical processes of snow and stratigraphy and metamorphism. Interpretation of ice sheet stratigraphy in terms of paleoenvironment. Dynamic metamorphism from ice flow. Structures formed at freezing interfaces. Structure of river, lake and sea ice. Relationship between structures and bulk physical properties. Offered jointly with ESS 534. (Offered alternate years.)
Prerequisites: Permission of instructor.

514 ICE AND CLIMATE (3)
Examines the role of ice and snow in climate. Polar climate dynamics. Polar-global interactions. Modeling snow cover, sea ice, and ice-sheet mass balance and flow in the climate system. Offered jointly with ESS 535. (Offered alternate years.)
Prerequisite: Permission of instructor.

520 ATMOSPHERIC SCIENCES COLLOQUIUM (1) AWSp
Seminars on current research in advanced topics related to atmospheric sciences; conducted by faculty and visiting scientists/professors. Includes presentations of doctoral dissertations by department graduate students. For Atmospheric Sciences graduate students only. CR/NC
Prerequisite: Permission of department.

521 SEMINAR IN ATMOSPHERIC AND CLIMATE DYNAMICS (*) AWSp
Directed at current research in the subject. For advanced students. CR/NC
Prerequisite: Permission of instructor.

523 SEMINAR IN ATMOSPHERIC PHYSICS AND CHEMISTRY (*) AWSp
Directed at current research in the subject. For advanced students. CR/NC
Prerequisite: Permission of instructor.

524 SEMINAR IN CLIMATE DYNAMICS AND ENERGY TRANSFER (*) A
Directed at current research in the subject. For advanced students. CR/NC
Prerequisite: Permission of instructor.

525 SEMINAR - TOPICS IN ATMOSPHERIC CHEMISTRY (1-3, max. 6) W
Seminar for atmospheric scientists, chemists, and engineers in problems associated with the chemical composition of the atmosphere. Topics range from the natural system to urban pollution and global atmospheric change. Faculty lectures and student participation. Offered jointly with CEE 553. CR/NC
Prerequisite: CEE 301 or permission of instructor.

532 ATMOSPHERIC RADIATION: INTRODUCTION (3) W
Fundamentals of radiative transfer; absorption and scattering by atmospheric gases; elementary applications to constraints on the thermal structure, photochemistry, and remote sensing.
Prerequisite: PHYS 323 or permission of instructor.

533 ATMOSPHERIC RADIATION: ADVANCED (3) A
Optical properties and particle absorption and scattering; solutions of radiative transfer equation in multiple scattering atmospheres; applications to atmospheric and surface energy balance and remote sensing.
Prerequisite: ATMS 532/ESS 571 or permission of instructor.

534 REMOTE SENSING OF THE ATMOSPHERE AND CLIMATE SYSTEM (3)
Satellite systems for sensing the atmosphere and climate system. Recovery of atmospheric and surface information from satellite radiance measurements. Applications to research. (Offered alternate years.)
Prerequisites: 532 or 533.

535 CLOUD MICROPHYSICS AND DYNAMICS (3) Sp
Basic concepts of cloud microphysics, water continuity in clouds, cloud dynamics, and cloud models. Offered jointly with ESS 573.
Prerequisite: 501 or permission of instructor.

536 MESOSCALE STORM STRUCTURE AND DYNAMICS (3) Sp
Techniques of observing storm structure and dynamics by radar and aircraft, observed structures of precipitating cloud systems, comparison of observed structures with cloud models. (offered alternate years)
Prerequisite: 535/ESS 573.

542 SYNOPTIC AND MESOSCALE DYNAMICS (3) Sp
Quasi-geostrophic theory, baroclinic instability, symmetric instability, tropical disturbances, frontogenesis, orographic disturbances, convective storms.
Prerequisites: 509/ OCEAN 512 and AMATH 402 or equivalents.

545 GENERAL CIRCULATION OF THE ATMOSPHERE (3) Sp
Requirements of the global angular momentum heat, mass and energy budgets upon atmospheric motions as deduced from observations. Study of the physical processes through which these budgets are satisfied.
Prerequisite: 509,/OCEAN 512 or permission of instructor.

547 BOUNDARY LAYER METEOROLOGY (3) Sp
Turbulence, turbulent fluxes, averaging. Convection and shear instability. Monin-Obukhov similarity theory, surface roughness. Wind profiles. Organized large eddies. Energy fluxes at ocean and land surfaces, diurnal cycle. Convective and stable stratified boundary layers. Cloud-topped boundary layers. Remote sensing. Boundary layer modeling and parmeterization. (Offered alternate years)
Prerequisite: 505; AMATH 505 or OCEAN 511.

551 ATMOSPHERIC STRUCTURE AND ANALYSIS I: SYNOPTIC SCALE SYSTEMS (4)
Extratropical cyclones and cyclogenesis. Jet streams. Upper waves in the westerlies. Diagnosis of vertical motions. Fronts and frontogenesis. (Offered alternative years).
Prerequisite: 502 and 509 or OCEAN 512.

552 OBJECTIVE ANALYSIS (3) W
Review of objective analysis techniques commonly applied to atmospheric problems; examples from the meteorological literature and class projects. Superposed epoch analysis, cross-spectrum analysis, filtering, eigenvector analysis, optimum interpolation techniques.

553 ATMOSPHERIC STRUCTURE AND ANALYSIS II: NON-CONVECTIVE MESOSCALE CIRCULATION (3) W
Thermally forced circulation systems, including sea/land breezes and mountain/valley winds. Topographic deflection, channeling and blocking in mesoscale flows. Analysis and forecasting of local mesoscale phenomena. (Offered alternate years.)

554 PALEOCLIMATE PROXIES (3)
Provides a critical evaluation of the most commonly applied paleoclimate proxies from the ocean, land, and ice sheets. Offered: jointly with ESS 554/OCEAN 554; alternate years.

555 PLANETARY ATMOSPHERES (3) A or W
Problems of origin, evolution and structure of planetary atmospheres, emphasizing elements common to all; roles of radiation, chemistry and dynamical processes; new results on the atmospheres of Venus, Mars, Jupiter and other solar system objects in the context of comparative planetology. Offered jointly with ASTR 555/ESS 581. (Offered alternate years.)

556 PLANETARY SCALE DYNAMICS (3) Sp
Zonally symmetric circulations, planetary waves, equatorial waves, dynamics of the middle atmosphere, trace constituent transport, nonlinear aspects of atmospheric flows. (Offered alternate years.)
Prerequisites: 542 or permission of instructor.

558 ATMOSPHERIC CHEMISTRY (3) Sp
Photochemistry of urban, rural, and marine tropospheric air, and of the natural and perturbed ozone in the middle atmosphere. Unity of the chemistries in these apparently different regimes.
Prerequisites: 458 or 501 or CHEM 457 or permission of instructor.

559 CLIMATE MODELING (3) Sp
Principles of Earth system modeling. Emphasis on atmosphere, ocean sea ice, and land-surface components. Climate forcing. Appropriate use of models. Topics of current interest including carbon cycle, atmosphere chemistry, and biogeochemistry.
Prerequisite: either ATM S/OCEAN/ESS 587, ATM S 504 or ATM S 505. Offered jointly with ESS 559/OCEAN 558. (Offered alternate years.)

560 ATMOSPHERE/OCEAN INTERACTIONS (3) Sp
Observations and theory of phenomena of the coupled atmosphere-ocean system. El Nino/Southern Oscillation; decadal tropical variability; atmospheric teleconnections; midlatitude atmosphere-ocean variability. Overview of essential ocean and atmospheric dynamics, where appropriate.Offered jointly with OCEAN 560. CR/NC.
Prerequisites: 509/ OCEAN 512. Alternate years.

564 ATMOSPHERIC AEROSOL AND MULTIPHASE ATMOSPHERIC CHEMISTRY (3) W
Physics and chemistry of particles and droplets in the atmosphere. Statistics of size distributions, mechanics, optics and physical chemistry of atmospheric aerosols. Brownian motion, sedimentation, impaction, condensation and hydroscopic growth. (Offered alternate years.)
Prerequisite: Permission of instructor.

571 ADVANCED PHYSICAL CLIMATOLOGY (3) A
Physical processes that determine the climate of Earth and its past and future changes. Greenhouse effect. Climate modeling. Radiative and dynamical feedback processes. Orbital parameter theory. Critical analysis of climate change predictions. (Offered alternate years.)
Prerequisite: Permission of instructor.

575 LARGE SCALE DYNAMICS OF THE TROPICAL ATMOSPHERE (3) W
Observations and underlying dynamics of large-scale tropical circulations. Factors that determine regions of large-scale persistent precipitation in the tropics, thermal forcing of atmospheric circulations by these regions, and temporal variability of the forcing and response. (Offered alternate years.) CR/NC
Prerequisites: 509/ OCEAN 512 and 542.

581 NUMERICAL ANALYSIS OF TIME DEPENDENT PROBLEMS (5) Sp
Numerical methods for time-dependent ordinary and partial differential equations, including explicit and implicit methods for hyperbolic and parabolic equations. Stability, accuracy, and convergence theory. Spectral and pseudospectral methods. Offered jointly with AMATH 586/MATH 586.
Prerequisite: Familiarity with partial differential equations and Matlab. AMATH 581 or AMATH 584 strongly recommended.

582 ADVANCED NUMERICAL MODELING OF GEOPHYSICAL FLOWS (3)
Topics of current interest including: efficient time differencing, semi-implicit and multiple time step techniques. Semi-langrangian schemes. Treatment of poorly resolved gradients. Flux-corrected transport. Positive definite advection schemes. Aliasing error and nonlinear instability. Wave permeable boundary conditions. (Offered alternate years). Prerequisite: 581 and AMATH 586 or MATH 586.

585 CLIMATE IMPACTS OF THE PACIFIC NORTHWEST (4) Sp
Knowledge of past/future patterns of climate to improve Pacific Northwest resource management. Topics include the predictability of natural/human-caused climate changes; past societal reactions to climate impacts on water, fish, frest, and coastal resources; how climate and public policies interact to affect ecosystems and society. Offered jointly with ESS/ENVIR/SMA 585.

586 CURRENT RESEARCH IN CLIMATE CHANGE (2)
Weekly lectures focusing on a particular aspect of climate (topic to change each year) from invited speakers (both UW and outside), plus one or two keynote speakers, followed by class discussion. Offered jointly with OCN 586 and ESS 586.

587 CLIMATE DYNAMICS (3) A
Description of Earth's climate system; distribution of temperature, precipitation, wind, ice, salinity and ocean currents; fundamental processes determining Earth's climate; energy and constituent transport mechanisms; climate sensitivity; natural climate variability on interannual to decadal time scales; global climate models; predicting future climate. Offered jointly with OCEAN 587 and ESS 587.

588 THE GLOBAL CARBON CYCLE AND CLIMATE (3) W
Oceanic and terrestrial biogeochemical processes controlling atmospheric CO_2 and other greenhouse gases. Records of past changes in the earth's carbon cycle from geological, oceanographic and terrestrial archives. Anthropogenic perturbations to cycles. Develop simple box models, discuss results of complex models. Offered jointly with OCEAN 588 and ESS 588.

589 PALEOCLIMATOLOGY: DATA MODELING AND THEORY (3) Sp
Evidence for past changes in land and sea surface temperature, in precipitation and atmospheric dynamics, and in ocean circulation: both long and interannual timescales. Paleoclimate modeling and theory. Time series analysis and climate noise. Rapid climate change. Statistical reconstruction of interannual variability. Offered jointly with OCEAN 589 and ESS 589.

591 SPECIAL TOPICS IN ATMOSPHERIC SCIENCES (1-4, max. 9) AWSp
Lecture series on topics of major importance in the atmospheric sciences.
Prerequisite: Permission of instructor

593 CLIMATE SCIENCE SEMINAR (1) W
Focuses on how to communicate climate science to many different audiences through careful construction of figures and through written and oral communication. Credit/no credit only. Offered: jointly with ESS 593/OCEAN 593.

596 CLIMATE SCIENCE CAPSTONE PROJECT (1-5, max. 5) AWSpS
Climate capstone directed by a mentor, may be a group effort, and may encompass curriculum development, internships, workshop organization, etc., capturing interdisciplinary aspects of climate science and effective communication of climate science. Offered: jointly with ESS 596/OCEAN 596.

600 Independent Research (*) CR/NC

700 Master's Thesis (*)

800 Doctoral Dissertation (*)

*variable credit