GRADUATE STUDENT HANDBOOK

FOR THE SCHOOL OF

EARTH AND ATMOSPHERIC SCIENCES

GEORGIA INSTITUTE OF TECHNOLOGY

Doctoral and Master's Programs

This Handbook, prepared by the School's Graduate Studies Committee, states the policies and procedures of the School of Earth and Atmospheric Sciences. All rules and policies of the Institute take precedence in any conflict, real or apparent, with statements contained herein.

Latest Revision 11 August, 2009

TABLE OF CONTENTS

I. General Student Information

Permanent (Thesis) Advisor

Prior to enrolling in the graduate program, all incoming students are assigned a *Temporary Advisor* who will assist the student with registration during his/her first semester of study and will help the student select a *Permanent Advisor*. The *Permanent Advisor* will also be the *Thesis Advisor* for the student's Thesis research. Hereinafter the term *Advisor* will be used to designate the Permanent or Thesis Advisor.

Each student must select an Advisor and major field of study by the end of his/her first semester of residence in order to register for succeeding semesters. The Advisor must agree to serve as such and the agreement will be signified by a signed form (see attached sample in Appendix). The *Advisor Form* will be incorporated into the student's file. A newly signed Advisor Form must accompany any subsequent change of Advisor.

Evaluation of Progress

Each student and Advisor must submit an *Annual Evaluation of Progress* (AEP) to the *Graduate Coordinator* by April 15th of each year (See form in Appendix). This form will be used by the Graduate Coordinator to insure that satisfactory progress is being made towards the degree and to help determine whether the student receives continued financial support. If the AEP has not been completed, a hold will be placed on the student's registration for courses. The student may be asked to meet with the Graduate Coordinator and/or the *Graduate Studies Committee*, as appropriate, to discuss his/her progress and determine what actions need to be taken.

Course Registration

All M.S. and Pre-Comps Ph. D. students must have their *Registration Form* approved by their Advisor and the Graduate Coordinator to remove the Hold on their Registration. The faculty member responsible for supervising a Special Problems Course must approve the Registration Form of each student registering for that course.

Graduate Assistants must be full time students and must register for at least 12 hours of course work on a letter-grade or pass-fail basis. With permission, up to three hours may be taken as Audit. These students must maintain a full-time (12-hour) course load. Dropping to below 12 hours after registration, unless approved in advance by the Graduate Coordinator, will result in termination of financial support. Students are encouraged to register for more than the minimum of 12 hours credit, either by taking thesis hours or special problems.

Financial Support

The annual stipends for all Graduate Assistantships (GRAs and GTAs) are set by the faculty of the School of Earth and Atmospheric Sciences (EAS) and published before the start of Fall Semester. To continue to receive financial support, a student must maintain a GPA of 3.0 in EAS courses and remain in good standing with the School and Institute. The Graduate Coordinator will review the file of any student failing to meet these requirements and, in conjunction with the Graduate Studies Committee, may recommend to the *School Chair* that financial support be terminated.

A student requesting support from the School as a Graduate Teaching Assistant should send a written memo or an email to the Graduate Coordinator by the middle of the semester

prior to that during which TA support is desired. For students seeking TA support in Fall, this request should accompany the AEP. Students working towards a Ph.D. degree normally will not be given GTA/GRA support beyond **five** years of study.
Students working towards a M.S. (Thesis) degree normally will not be given GTA/GRA support beyond **two** years of study. Students working towards a M.S. (non-Thesis) degree are not normally eligible for Graduate Assistantship support.

Graduate Assistantships are normally half-time (1/2) appointments in the Institute. One-third (1/3)-time appointments are permitted only upon written approval of the Advisor, the Graduate Coordinator, the Graduate Studies Committee, and the *School Chair*. One-half time Graduate Assistants cannot simultaneously be employed at any other job. A one-third time Graduate Assistant cannot be employed for more than 7 hours/week at any other job without the approval of his/her Advisor and the Graduate Studies Committee.

Honor Code

The School of Earth and Atmospheric Sciences strictly enforces the Honor Code of the Institute.

English Proficiency

Students whose speaking, writing and reading skills in English are not satisfactory upon entering must achieve English proficiency by the end of their first year in the program.

II. M.S. PROGRAM REQUIREMENTS

Designated and Undesignated Degree

The School of Earth and Atmospheric Sciences offers two M.S. Degrees: (1) the **Designated Master's Degree** (thesis program) which leads to a M.S. in Earth and Atmospheric Sciences and requires completion of a Master's thesis and (2) the **Undesignated Master's Degree** (non-thesis program) which leads to a M.S. degree. The thesis program is strongly encouraged. The non-thesis degree option requires the permission of the School Chair.

Requirements

The Institute's credit hour requirements for both the Thesis and Non-Thesis Master's degree are explicitly stated in the Georgia Tech General Catalogue. In addition to the Institute requirements, EAS requires students pursuing a non-thesis master to take three credit hours of special problems.

Students pursuing the thesis option must submit a thesis based on their research accomplishments to a Thesis Reading Committee (TRC). This committee consists of at least three faculty members including the student's advisor. Students may submit their final version of their thesis to the library after it has been signed and approved by the TRC.

General requirements for both options include a minimum of 30 credit hours. All courses must be at the 4000 level or above. A minimum of 12 EAS course credit hours must be taken for a letter grade at the 6000 level or above. A summary of minimum course requirements for both the thesis and non-thesis options are given below.

	thesis	non-thesis
EAS course credit hours (graded) at 6000-level or above	12	12
Elective credit hours in major area at 4000-level or above	6	6
Elective course credit hours at 6000-level or above	0	9
Special Problems – EAS 8901	0	3
Undesignated credit hours	6	0
EAS 7000 (M.S. thesis credit hours)	6	0
Total credit hours	30	30

A maximum of 3 course credit hours may be taken under the pass fail designation. EAS 7000 is only taken on a pass/fail basis and cannot be used to fulfill the credit hour requirement for a non-thesis degree.

Students who want to transition to the Ph.D. program must petition to the Graduate Studies Committee. The student's petition should be accompanied by a supporting letter from his/her Advisor.

III. Ph.D. PROGRAM REQUIREMENTS

All Ph.D. students must fulfill the EAS course and academic breadth requirements and the Institute Minor course requirement. In addition, the student must pass the Comprehensive Examination. To complete the Ph.D., the student must complete the Minor requirement, write his/her Doctoral Dissertation, and successfully defend it before the Final Doctoral Examining Committee. A checklist of the required steps for the Ph.D. is provided in the Appendix along with the necessary forms.

EAS Course Requirements

Ph.D. students must complete at least 15 credit hours on a letter grade basis of EAS courses at the 6000 level or above. Seminar classes, special problems courses, and thesis hours can not be counted towards this total. Special topics classes may be credited to this total with approval of the Graduate Coordinator.

Minor Course Requirement

The Institute requires doctoral students to complete at least nine semester hours of work in *related* courses outside the student's Ph.D. research area (defined as one of the primary research areas listed on the EAS web page). The minor field can consist of courses from more than one School, as long as the courses are related. Students are allowed to use EAS courses to satisfy this requirement (e.g., a student performing research in geochemistry could satisfy the minor requirement with geophysics courses). Additional details are found in the Institute catalog. In certain cases incoming Ph.D. students with prior graduate training may apply previously earned graduate credit hours toward the minor requirement. In all cases minor course credit hours will not count toward fulfillment of the 15 credit EAS course requirement. The student's plan for satisfying the minor field requirement must be approved by the EAS Graduate Coordinator prior to the completion of the comprehensive examination. Once the student has completed the minor requirement, the EAS Graduate Coordinator sends a confirmation, accompanied by course grades, to the Institute Graduate Office for final approval and recording.

Academic Breadth Requirement

In recognition of the increasing interdisciplinary nature of research in Earth and Atmospheric Sciences, the EAS Ph.D. program incorporates an academic breadth component. This requirement, which provides students with a broader context for their own disciplinary research, is satisfied by fulfilling at least one of the following three options:

(1) The student spends one semester as a Graduate Teaching Assistant for EAS 1600, 1601, or 2600. Participation in this option requires lecture attendance.

(2) The student chooses an internal (EAS) minor track to satisfy the Institute minor requirement (discussed above). As per Institute requirements, the internal minor must be distinct from the student's specific Ph.D. research area. Suggested internal minor tracks (including course requirements) are listed on the EAS web page. Example cases include:

a) An atmospheric chemistry student can pursue an internal minor in remote sensing
b) A climate dynamics student can pursue a internal minor in environmental chemistry
c) A counterexample: An atmospheric chemistry student is not be permitted to pursue an internal minor in air quality (which is insufficiently distinct).

This option is generally not available to incoming students who choose to satisfy the Institute minor requirement using prior graduate training outside of Earth and Atmospheric Sciences (For example, an incoming student with an M.S. in physics who chooses to minor in physics on the basis of previous graduate coursework).

(3) A third option is available to students who prefer not to pursue either the teaching assistant or internal minor options. Students selecting this option must take 2 or more EAS courses (one at the 3000 level or above; the second at the 6000 level or above) from research areas outside the student's Ph.D. research area. As an example, a geophysics student could take courses in climate dynamics and geochemistry to fulfill this requirement.

In all cases the student's plan for satisfying the academic breadth requirement must be approved by the Graduate Coordinator prior to the completion of the comprehensive exam.

Comprehensive Examination

The Comprehensive Examination consists of a thesis proposal and a two-step written and oral examination. The written examination is composed of a series of problems formulated by the student's examining committee. The oral examination covers the subject matter of the thesis proposal, written examination and other general knowledge in the student's research field.

Each student must select a permanent thesis advisor and major field of study prior to the end of his/her first semester. The student will be provided with academic guidelines for the chosen major field of study. The guidelines will include a recommended sequence of courses and a summary list of Essential Knowledge for the major field of study. The Essential Knowledge lists for major EAS disciplines are provided in Appendix.

The Comprehensive Examination Committee (CEC) must be formed for each student by April 15 following the first full semester in residence. The CEC will consist of the student's permanent advisor, two academic faculty members chosen by the student from the student’s Thesis Advisory Committee, and two academic faculty members appointed by the Graduate Studies Committee (GSC). One of the GSC appointed members will be the committee chair and the other from a research area outside the student’s area. The student’s selections must be reported to the GSC no later than March 1 following the first full semester in residence. Thereafter, the student, in collaboration with his/her advisor, will formulate (a) a thesis proposal abstract and (b) a Essential Knowledge list (based upon the student’s thesis research area). Students may adopt one of the existing Essential Knowledge lists for major disciplines or develop a tailored list by expanding upon the discipline’s existing Essential Knowledge list. The thesis proposal abstract and Essential Knowledge list must be submitted to, and approved by, the CEC prior to the end of the Fall semester following the first full year in residence (summers excluded). If a student is unable to meet this deadline, he/she will be required to complete a thesis M.S. degree within EAS (prior to the end of the succeeding summer semester) in order to proceed to the comprehensive exam. Students transitioning from a thesis M.S. degree to the PhD program must take the comprehensive exam no later than the Spring Semester of their third year in residence.

The thesis proposal should be in the general area of the student's PhD thesis research and must incorporate all of the following four elements:

a) Scientific background and motivation. This element must provide a critical review of relevant past literature and how the student’s new results and proposed future research relate to these previous research efforts by other scientists.

b) Preliminary research. New research results are presented and interpreted in this element.

c) Synthesized discussion/conclusions. The student must provide a synthesizing summary discussion of his/her new research that assesses the (i) immediate scientific implications of the new research, (ii) broader impacts, and (iii) remaining scientific questions to address.

d) Future research plans. The student must provide a detailed and structured overview of his/her future research plans in this element.

The paper will be evaluated on the basis of its scientific quality, thoroughness, and clarity.

Scientific discussions with faculty members during the development of the thesis proposal are permitted and strongly encouraged. This includes topic selection, reference materials suggestions, and general outline development. Although faculty may provide feedback to students regarding their research results, the thesis proposal must be the work of the student and *faculty members are not permitted to directly contribute to the creation or editing of the thesis proposal document*. However, the student is permitted and strongly encouraged to obtain input from other students regarding matters of clarity, style and grammar. Citation of source materials is mandatory, and plagiarism will result in failure of the examination.

The manuscript body is limited to 35 pages; longer documents will not be accepted for review by the CEC. The text must be double-spaced with a minimum font size of 12 point and 1 inch margins. Each paper must be singled-sided and include an abstract and a table of contents. Figures (with captions) shall be placed in sequence at the end of the paper and references should be formatted using either American Meteorological Society or American Geophysical Union journal specifications. The reference list is not included in the page limit.

The thesis proposal must be submitted to the CEC by March 1 following the third full semester in residence in the Ph.D. program (summers excluded). The paper will then be evaluated by the CEC with each committee member providing a written review to the committee chairman. The written examination will take place during the week prior to Spring Break and will be followed by an oral examination that must be scheduled to take place prior to April 15.

The written examination is a one day, closed-book exam consisting of a collection of 5 synthesizing problems formulated by each respective CEC member based on the student’s thesis proposal and Essential Knowledge list. The problems are aimed at assessing the adequacy of the student’s foundational knowledge base within his/her research field. Each student is required to answer 4 out of the 5 problems. The subsequent oral examination will consist of two parts. The first part is a 20 minute public presentation of the thesis proposal to the examining committee and other interested faculty and students. Students who have not yet taken the comprehensive examination are especially encouraged to attend the oral presentation and the following 15-20 minute open question period, during which the student will answer questions from the general audience. The second part of the examination is a closed session in which members of the CEC will question the student regarding the thesis proposal, written examination, and other general knowledge in the student's chosen research field. The entire oral examination takes about 3 hours. After the closed session is completed, the student will be excused while the examining committee votes on the outcome of the examination. A pass vote from 3 of 5 CEC members is required for successful completion of the comprehensive examination. The student will be notified immediately of the outcome. Students who fail the exam will not be advanced to candidacy in the Ph.D. program. In the case of failure, the CEC will also provide the student with a recommendation on how to proceed forward.

Timeline Associated with Comprehensive Examination

Schedule	
Fall, First year	Student chooses a permanent academic advisor and the major field of the study by the end of Fall Semester. *Student selects the major field of his/her PhD.* *Depending on the selected field, students are provided with guidelines regarding the recommended sequence of courses (including required course on Scientific Writing) and Essential Knowledge Lists (developed for each major discipline).*
Spring, First year	Comprehensive Examination Committee (CEC) is formed for each student by Apr. 15.
Summer, First year	Student and his/her advisor tailor Essential Knowledge list in accord with student's thesis research area
Fall, Second year	*Required course on Scientific Writing must be taken by Fall of Second Year.* Student requests CEC approval of his/her abstract of the thesis proposal and the Student's Essential Knowledge list (by the end of Fall Semester). If a student is not ready for the examination, he/she must complete a thesis M.S. by the end of Summer Semester of the second year.
Spring, Second year	Student submits his/her thesis proposal (by March 1) Two-step Examination: 1. Take written examination (one day during the week prior to Spring Break) (5 questions:1 by each member of the committee; student must answer 4 questions) 2. Oral examination (presentation of the student's thesis proposal followed by questions and discussion of thesis proposal and written examination) must be completed by April 15. *If not pass, CEC decides among retake, conditional pass, or terminal MS recommendation.*

Admission to Candidacy

After completing all EAS course requirements and passing the comprehensive examination a student may be admitted to candidacy. For admission to candidacy the student must file with the School Chair and the Office of Graduate Studies and Research the "Request for Admission to Candidacy" form.

The Doctoral Examination (Thesis Defense)

After the Thesis Advisory Committee finds the dissertation satisfactory, it schedules the candidate for an oral examination (Thesis Defense). The Final Doctoral Examination Committee, as approved by the Office of Graduate Studies and Research, will conduct the examination. The location, title of thesis, and members of the Final Doctoral Examination Committee must be submitted to the Office of Graduate Studies at least 15 working days prior to the defense. Additional details are provided in the Catalog.

IV. Forms and Committees

Ph. D. Students

Request for Admission to Candidacy

This form must be completed for admission to candidacy. The student's Thesis Advisory Committee and School Chair and the Graduate Studies Office must approve the form.

Petition for Degree

This form must be submitted early in the semester prior to the one in which the student expects to graduate.

Thesis Advisory Committee

The Thesis Advisory Committee consists of at least three persons, one of whom is the Thesis Advisor. This Committee should be formed during the second semester of residence, as it may help in part to guide the Comprehensive Exam paper as well as thesis research. The Thesis Advisory Committee signs the "Request for Admission to Candidacy" form and submits it to the Graduate Office. The Thesis Advisory Committee provides advice and guidance during the research and is charged with approving the dissertation when the research is completed and presented as the doctoral dissertation. When the Thesis Advisory Committee considers the dissertation to be satisfactory, a recommendation is made to the Dean of the Graduate Division for the appointment of the second committee, which is called the Final Doctoral Examination Committee.

Final Doctoral Examination Committee

The Final Doctoral Examination Committee, which consists of at least five persons, always contains the Thesis Advisory Committee members and others, as appropriate, who are recommended by the School to the Dean of the Graduate Division for approval. At least one member of the Final Doctoral Examination Committee must be from a School or College other than the unit in which the student is enrolled. The School of Earth and Atmospheric Sciences strongly recommends that at least one member of the Final Doctoral Examination Committee be from a university or research establishment other than Georgia Tech.

It is permissible to appoint a Thesis Advisory Committee which consists of five or more persons and to recommend this committee to serve as the Final Doctoral Examination *Committee*, provided the constraints above are met for both Committees.

M.S. Students

Approved Program of Study

The *Program of Study* form lists the courses the student proposes to use to satisfy the M.S. degree requirements. It should be completed by the second semester of the program, approved by the School Chair and submitted to the Registrar. This form must be submitted before or simultaneously with the **Petition for Degree** form.

Petition for Degree

This form must be submitted early in the semester prior to the one in which the student expects to graduate.

Request for Approval of Thesis Topic

This form should be completed once reasonable progress has been made on thesis research. The form must be approved by the student's *Thesis Reading Committee* and School Chair.

Thesis Reading Committee

The Thesis Reading Committee consists of at least three members, one of whom is the Thesis Advisor. The majority of Committee members must be members of the Academic Faculty. The Thesis Reading Committee is formed as soon as possible after the student initiates his/her thesis research. The Thesis Reading Committee provides advice and guidance during the research and is charged with approving the thesis when the research is completed and presented in partial fulfillment for the Master's degree. When the Thesis Reading Committee considers the thesis to be satisfactory, the candidate may prepare the final version for formal signatures and submission to the library.

V. Additional Information

Additional information regarding guidelines and procedures of the School and Institute can be obtained from the Graduate Coordinator's office or the Office of Graduate Studies. These include:

(1) The Comprehensive Exam
(2) The Georgia Tech General Catalog
(3) Georgia Tech’s Guidelines for Ph.D. Dissertation Research
(4) Manual for Graduate Theses

VI. Appendices

Ph.D. Milestone Checklist

M.S. Milestone Checklist

Advisor Form

Annual Evaluation of Student Progress Form

Advisor Registration Form -- *Advisor* approval of Course Schedule for each semester; present to the *Graduate Coordinator* for removal of School Registration Hold

Note all Institute forms required by the can be found at:
http://www.grad.gatech.edu/thesis/forms.html

Ph.D. MILESTONE CHECKLIST

Milestone Activity	Target Completion Time	Date Completed
Select Permanent Thesis Advisor:	Prior to end of first semester	________________
Select major field of study:	Prior to end of first semester	________________
Select Thesis Advisory Committee:	Prior to March 1 of first year	________________
Formulate CEC*:	Prior to April 15 of first year	________________
Annual EAS evaluation of progress:	Annually: prior to April 15	________________
Construct tailored EKL**:	Prior to start of third semester	________________
Take Scientific Writing Course:	Prior to end of third semester	________________
Obtain approval of EKL and thesis proposal abstract from CEC:	Prior to end of third semester	________________
Submit plans for Academic Breadth and Minor Course Requirements to EAS graduate coordinator:	Prior to end of third semester	________________
Submit PhD thesis proposal:	Prior to March 1 of second year	________________
Take Comprehensive Examination:	Prior to April 15 of second year	________________
Submit/present paper at national/ international scientific meeting:	Prior to end of second year	________________
Submit Admission to Candidacy:	After comprehensive exam	
Annual meeting with Thesis Advisory Committee to discuss research progress:	Annually after year 2	
Submit first-authored paper for publication in peer-reviewed scientific journal:	Prior to end of third year	________________
Complete PhD Minor:	Prior to end of 6th semester	________________
Write Thesis (Obtain Manual of Graduate Theses from Office of Graduate Studies):	During fifth year in residence	________________
Submit 2nd first-authored paper for publication in peer-reviewed scientific journal:	One semester prior to graduation	________________
Complete Degree Petition:	One semester prior to graduation	________________

Formulate Final Doctoral Examination Committee for Ph.D. defense:

One semester prior to graduation ___________________

Notify Office of Graduate Studies of scheduled thesis defense, including date, time, location, thesis title, and members of Final Doctoral Examination Committee (Thesis Advisor/Graduate Coordinator): At least 14 days prior to thesis defense ___________________

Distribute thesis to Final Doctoral Examination Committee:

At least 7 days prior to thesis defense ___________________

Defend thesis Prior to end of fifth year in residence ___________________

Submit final version of thesis plus required forms to Graduate Thesis Office

Deadlines vary: Check GT Calendar ___________________

*Comprehensive Examination Committee (Thesis Advisory Committee + 2 members chosen by EAS Graduate Studies Committee.

**Essential Knowledge List (for purposes of comprehensive examination).

M.S. MILESTONE CHECKLIST

Milestone Activity	Target Completion Time	Date Completed
Select Thesis Advisor:	Prior to end of first semester	________________
Select Thesis Reading Committee:	Prior to end of second semester	________________
Approval of MS Program of Study:	Prior to end of second semester	________________
Annual EAS evaluation of progress:	Annually: prior to April 15th	________________
Approval of MS thesis topic:	Prior to end of third semester	________________
Complete Degree Petition:	One semester prior to graduation	________________
Write Thesis (Obtain Manual of Graduate Theses from Office of Graduate Studies):	During second year in residence	________________
Distribute thesis to Thesis Reading Committee:	1 month prior to thesis submission	________________
Complete Certificate of Thesis Approval (signed by Thesis Reading Committee and Graduate Coordinator):	1 week prior to thesis submission	________________
Submit final version of thesis plus required forms to Graduate Thesis Office	Deadlines vary: Check GT Calendar	________________

SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES

Permanent Advisor Form (Due at the end of 1st semester)

Student Name: ________________________________

Major Field of Study: ___________________________

Advisor Name: ________________________________

I agree to serve as the *Permanent Advisor* for the above student.

Advisor's Signature: ____________________________ Date: ________________

Advisor will support: Yes ________ No _______ *Advisor's* Initials _______

Comments:

SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES

Annual Evaluation of Student Progress (Due April 15th)

Student's Name___________________________ Advisor's Name ____________________________

Status (%MS %Ph.D.) Year in Program (%1 %2 %3 %4 %5 %>5)

Comprehensive Exam (%NA %Pass %Fail)

Last Term GPA _____ Cumulative GPA___________

Current Support:
Project # ____________________________ State Funds _________________________________
Fellowship (name) ________________________ Other _____________________________________

Future Support:
Source(s): _______________________________ Probability (%Low %Average %High)

Progress Summary:
Course Work (%Excellent %Very Good %Good %Fair %Poor %NA)

Research (%Excellent %Very Good %Good %Fair %Poor)

Research Products:
Lectures ________ Proposals__________ Papers____________ Reports ___________

Only count research products in which the student made a major contribution. The full citation of each research product should be in the student's curriculum vita, which must be attached to this report.

Other Scholarly Student Activity:

Advisor's Recommendations and Comments:

_______________________________ ____________________
Student's Signature Date

_______________________________ ____________________
Advisor's Signature Date

EAS Registration Form

SCHEDULE: ___________________ **SEMESTER, 20**____________

Are you taking the Comprehensive Examination this term? Y/N
If "yes" sign up for EAS 7999 (P/F)

STUDENT NAME: ________________________ STUDENT NUMBER: _____________

COURSE	MEETING TIME	BASIS	CREDIT HOURS

Total (LG + P/F)* =________________

* Must be at least 12 hours to maintain classification as full-time student.

For EAS 7999A (Comp. Exam) and/or any Special Problems courses which must be approved by instructor:

COURSE	INSTRUCTOR	INSTRUCTOR'S SIGNATURE

Approval: _________________________ Date: ___________________

Faculty Advisor

_________________________ Date: ___________________

Graduate Coordinator

EAS SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES

Policy on Hour Loads for Graduate Students

The complete text of the Institute's policy on hour loads, which was approved by the Academic Senate on April 18, 2000, can be found at *http://www.grad.gatech.edu/ admin/hrload.html*.

EAS graduate students and their advisors will generally be able to follow the abbreviated procedures that are outlined here.

I. Part-time Students

The minimum load for part-time students is 3 credit hours on a letter grade, pass/fail, or audit basis.

II. Full-time Students

Graduate students holding appointments as graduate research assistants (GRA's) or as graduate teaching assistants (GTA's) must be full-time students. Full-time graduate students must be enrolled for 18 or more credit hours in the Fall and Spring semesters and for a maximum of 16 credit hours in the Summer term. **At least 12 credit hours must be taken on a letter grade or pass-fail basis.** Many possible combinations of scheduled courses, seminars, and research can be used to meet these credit hour requirements.

EAS graduate students are allowed to take 4000-level courses. Only courses taken on a letter grade or pass/fail basis can be used to meet Institute requirements for full-time status. If 4000-level courses are taken on a letter grade or pass/fail basis and have not been used previously to meet the requirements for another degree, those courses can also be used to satisfy Institute requirements for the undesignated or designated M. S. degree. With the approval of a doctoral student's thesis advisory committee and the Institute, 4000-level courses may be included in the nine semester hours of that student's academic minor.

All 6000-level EAS courses, when taken on a letter grade or pass/fail basis, can be used to meet Institute requirements for full-time status. Those courses can also be used to satisfy Institute requirements for the undesignated or designated M.S. degree.

The following courses at the 7000-9000 level are often used to partially satisfy requirements for a degree or for full-time status. Each of these courses is in some respects limited, so care must be exercised when using them to meet requirements for hour loads.

EAS 7000 – This course is taken on a pass/fail basis by students studying for the *designated* M. S. degree. These students are expected to devote an appropriate amount of time to thesis research under the supervision of a thesis advisor. It is the principal means by which these EAS students adjust their overall course load to meet the Institute's requirements for full-time enrollment.

EAS 7999 – This course is taken by doctoral students in the term in which they take the comprehensive examination. The course is taken on an audit basis and thus does not count toward the minimum requirement of 12 hours on a letter grade or pass/fail basis.

EAS 8001 – This course is a research seminar, and it can be taken as often as desired on a pass-fail basis. It counts toward the minimum requirement of 12 hours on a letter grade or pass-fail basis. Students seeking either the undesignated or designated M. S. degree can use up to three credit hours of EAS 8001 toward the M. S. degree.

EAS 8011 – This course is the EAS School seminar, and it should be taken every semester on a pass-fail basis. It counts toward the minimum requirement of 12 hours on a letter grade or pass-fail basis; however, this course cannot be used to meet degree requirements for either the undesignated or designated M. S. degree.

EAS 880x (x=1-6) – These are "Special Topics" courses for 1-6 credit hours. This designation will be used for a lecture-only course that is not already an officially approved course in the Institute catalog. Such courses should be taken for a letter grade.

EAS 882x (x=3-5) – These are "Special Topics with a Laboratory" courses for 3-5 credit hours. This designation will be used for a lecture-plus-laboratory course that is not already an officially approved course in the Institute catalog. Such courses should be taken for a letter grade.

EAS 890x (x=1-4) – These are "Special Problems" courses and the credit hours are variable from course to course and from term to term. This designation will be used for less structured intellectual activities that require supervision by a faculty member. For example, students studying for the *undesignated* M. S. degree are required to complete a six-hour Special Problems course. Activities that might be appropriate in a Special Problems course include literature research, laboratory research, computational projects, etc. Such courses should be taken for a letter grade

EAS 8997 – This course can be taken by students who are appointed as graduate teaching assistants in EAS. It can be taken only on an audit basis (up to nine credit hours per semester) and thus does not count toward the minimum requirement of 12 hours on a letter grade or pass/fail basis.

EAS 8998 – This course can be taken by students who are appointed as graduate research assistants in EAS. It can be taken only on an audit basis (up to nine credit hours per semester) and thus does not count toward the minimum requirement of 12 hours on a letter grade or pass/fail basis.

EAS 9000 – This course is taken on a pass/fail basis by students studying for the Ph.D. degree. Those students are expected to devote an appropriate amount of time to thesis research under the supervision of a thesis advisor. It is the principal means by which those students adjust their overall course load to meet the Institute's requirements for full-time enrollment.

Full-time students working exclusively on thesis research should be registered for 18 or more hours of 7000 or 9000 (Master's or Doctoral Thesis) in Fall and Spring semesters, and for up to 16 hours during Summer semesters.

A student may register for only one hour of Master's or Doctoral Thesis (7000 or 9000) during the semester of graduation. This exception may be used once for each degree.

Essential Knowledge Lists for Major EAS Disciplines

Essential Knowledge List for Atmospheric and Climate Dynamics students

This document serves as a summary of the background knowledge and skills that are expected of PhD level students studying atmospheric and climate dynamics at Georgia Tech. The information listed here is primarily covered in a series of “core” atmospheric science courses, advanced specialty courses, disciplinary seminar series, and individual research endeavors. Undergraduate technical training in chemistry, mathematics (up to vector calculus and ordinary differential equations) and calculus-based physics is assumed and is not explicitly covered in the core atmospheric science courses. The graduate-level core courses include Introductory Fluid Dynamics and Synoptic Meteorology, Introduction to Climate Change, Thermodynamics of Atmospheres and Oceans, and Environmental Data Analysis. Although these courses are not requirements per se, they are first-year graduate courses that most students will take.

Descriptive Knowledge of the Atmosphere and Climate
- Atmospheric composition and global vertical structure
- General circulation characteristics and seasonal variability
- Principal atmospheric scales and periodicities
- Extratropical weather systems: Air masses, fronts, cyclones, teleconnections and weather regimes
- Tropical weather systems: Tropical storms, monsoons, El Niño-Southern Oscillation, Intraseasonal Oscillation
- Atmospheric boundary layer
- Current and past climate characteristics
- Role of the atmosphere in the Earth System
- The atmospheric hydrologic and carbon cycles

Atmospheric Fluid Properties, Statics, and Kinematics
- Continuum hypothesis, ideal gas, equation of state
- Hydrostatic balance, pressure as a vertical coordinate, geopotential
- trajectories and streamlines, horizontal divergence and deformation, circulation and vorticity
- Nondivergent and irrotational flows, streamfunction and velocity potential
- Total derivative, material conservation principle and spatial advection
- Lagrangian and Eulerian characterizations of fluid time evolution

Thermodynamics of the Atmosphere and Ocean
- First Law of Thermodynamics, adiabatic processes in the atmosphere and ocean
- Entropy, Second Law of Thermodynamics, transport and time dependency
- Moist thermodynamic processes, static stability, buoyancy and convection
- Cloud and precipitation microphysics, cloud characteristics and radiative properties
- Surface exchange of heat and moisture, energy and salinity budget, ocean mixed layer

Fundamental Conservation Laws and Equations of Motion
- Conservation of mass: Continuity equation
- Conservation of energy: Thermodynamic equation
- Conservation of momentum: Navier-Stokes equations
- Inertial and noninertial reference frames
- Conservation of angular momentum and spherical coordinates
- Rotating reference frame, Centrifugal force, Coriolis force, effective gravity
- Primitive equations (rotating spherical reference frame)

Fundamental Approximations and Large-Scale Balanced Circulations
- Rossby number and scale analysis of the primitive equations
- Geostrophic approximation and the thermal wind equation
- Inertial, geostrophic, gradient and cyclostrophic circulations
- Quasi-geostrophic approximation and diagnostic application

- Circulation theorem, Vorticity and potential vorticity equations
- Large-scale dynamical balance for the tropical atmosphere

Atmospheric Waves and Instability
- Linear theory , perturbation methods and wave properties
- Acoustic, gravity, and Rossby waves,
- Equatorial wave theory: Rossby-gravity and Kelvin waves
- Baroclinic, barotropic, inertial and convective instability

Global Energy Cycle and Global Climate
- Global energy balance and the greenhouse effect
- Solar and infrared radiative transfer in the atmosphere
- Radiative-convective equilibrium and role of clouds
- Regional energy balance and poleward energy transport
- Surface energy balance and the atmospheric boundary layer
- Roles of hydrologic cycle and oceanic circulation in climate

General Circulation and Climate Variability
- Zonally averaged circulation and angular momentum budget
- Longitudinally varying seasonal mean circulation (stationary waves)
- Lorenz energy cycle and the role of large-scale Rossby waves
- Coupled climate variability (land surface, biosphere, cryosphere, thermohaline circulations, El Nino)
- External natural climate forcing (orbital and solar variability, volcanic eruptions)
- Anthropogenic influences (greenhouse gases, tropospheric & stratospheric ozone, sulfate aerosols)
- Climate feedback processes, climate sensitivity, and climate equilibria
- Numerical simulation and prediction of climate variability

Basic Computing and Mathematical Skills
- Needs will vary: Suitable combination of Matlab, IDL, Fortran, GrADS, Ferret, or similar
- Basic Unix/Linux, Unix shell scripting, operating on multi-dimensional datasets (e.g., netCDF, GRIB)
- Vector calculus operations, matrix and vector algebra, Taylor series, linear differential equation solutions
- Basic statistical inferences, data fitting and least square theory, time series analysis, regression analysis
- Spectral analysis, orthonormal functions, Fourier series, principle component analysis, wavelet analysis
- Numerical methods, discretization schemes, error and stability analysis, nonlinear systems, inverse methods

Specialized Skill Sets
- Mesoscale circulations: fronts and frontogenesis, symmetric instability, topographic waves, convective storms
- Tropical dynamics: Scale analysis, equatorial wave theory, steady forced motions, tropical cyclone physics
- Stratosphere: Ozone hole, stratospheric warmings, Brewer-Dobson circulation, annular modes, QBO

Key Textbook Resources
- An Introduction to Dynamic Meteorology, James R. Holton, Elsevier/Academic Press
- Global Physical Climatology, Dennis L. Hartmann, Elsevier/Academic Press
- Thermodynamics of Atmospheres and Oceans, Judith Curry and Peter Webster, Elsevier/Academic Press
- Discrete Inverse and State Estimation Problems, Carl Wunsch, Cambridge Press
- Statistical Methods in the Atmospheric Sciences, Daniel Wilks, Elsevier/Academic Press

Essential Knowledge List for Atmospheric Chemistry Students

This document serves as a summary of the background knowledge that is expected of PhD level students specializing in atmospheric chemistry at Georgia Tech. The information listed here as essential knowledge for all students is covered in four graduate courses: Atmospheric Chemistry, Thermodynamics of Atmospheres and Oceans, Atmospheric Aerosols, and Aerosols, Clouds, and Climate. Other courses that may be useful for some students depending on their background and research focus include Biogeochemical Cycles, Air Pollution Physics and Chemistry, and Atmospheric Radiative Transfer. Undergraduate technical training in chemistry, calculus-based physics, and mathematics (up to vector calculus and ordinary differential equations) is assumed and is not explicitly covered in graduate coursework. Students with no undergraduate training in Earth System Science would benefit from a TA assignment in one of the EAS freshman-level courses. Recommended textbooks for learning or reviewing essential knowledge topics are (1) *Introduction to Atmospheric Chemistry* by D.J. Jacob, Princeton University Press, 1999, and (2) *Atmospheric Chemistry and Physics, 2nd ed.*, by J.H. Seinfeld and S.N. Pandis, John Wiley & Sons, 2006.

All atmospheric chemistry students should be familiar with the following:

Basic Components of Earth System Science
- Freshman undergraduate level of understanding

Atmospheric Transport
- Specific topics and level of understanding as covered in Chapter 4 of Jacob.

Basics of Gas Phase Kinetics
- Bimolecular and termolecular reactions
- Pseudo-first order reactions and the concept of lifetime
- Steady state approximation

Basics of Photochemistry
- Beer-Lambert law
- The concept of the j-value
- Dependence of j-values on solar zenith angle
- Correspondence between absorption spectra and j(z)

Basics of Aqueous Phase and Multi-Phase Reaction Kinetics and Equilibria
- Acid-base equilibria
- Henry's law
- Mass transport limitations
- The resistor model for multi-phase kinetics
- Level of understanding of the above topics as covered in Chapters 7 and 12 of Seinfeld and Pandis

Simple Models for Describing Atmospheric Chemical Systems
- Box models
- Puff models
- Level of understanding of the above topics as covered in Chapter 3 of Jacob

Atmospheric Aerosol
- Source/sink mechanisms
- Characteristic size distributions
- Basic elements of aerosol microphysics including nucleation
- Condensation/evaporation and coagulation
- Aerosol thermodynamics
- Secondary organic aerosol (SOA) formation mechanisms and partitioning;
- Interaction of aerosols with radiation
- Level of understanding of the above topics as covered in Chapters 8−15 of Seinfeld and Pandis

Elementary Cloud Physics
- Basic mechanisms for cloud formation (the parcel model concept)

- Humidity variables
- Saturated adiabatic lapse rate
- Adiabatic liquid water content
- Convective cloud formation
- Köhler theory
- Level of understanding of the above topics as covered in Chapter 17 of Seinfeld and Pandis

Stratospheric Ozone Chemistry
- Chapman mechanism
- Catalytic cycles involving HO_x, NO_x, and halogen radicals
- Factors controlling efficiencies of catalytic cycles (null cycles and reservoir species)
- Antarctic ozone hole and stratospheric heterogeneous chemistry
- Sources of stratospheric pollution
- Ozone depletion potentials
- Level of understanding of the above topics as covered in Chapter 10 of Jacob

Oxidizing Capacity of the Troposphere
- Chemistry of the coupled O_3, HO_x, NO_x, CH_4 system
- Chemical regimes for net photochemical production/destruction of tropospheric O_3
- Budgets of HO_x, NO_x, CH_4, and CO
- Level of understanding of the above topics as covered in Chapter 11 of Jacob

Urban and Regional Air Quality
- NO_x– and hydrocarbon–limited regimes for O_3 production
- Role of aerosols in air quality
- Sources of primary aerosol
- Mechanisms for formation of SOA in polluted environments
- Level of understanding of the above topics as covered in Chapter 12 of Jacob

Chemistry and Climate
- The greenhouse effect
- The concept of radiative forcing
- Global warming potentials
- Stratospheric cooling by greenhouse gases
- The indirect effect of aerosol on climate
- Level of understanding of the above topics as covered in Chapter 7 of Jacob and Chapters 23 & 24 of Seinfeld and Pandis

The following material is essential knowledge for students in specific research groups

Radiative Transfer
- Rayleigh scattering
- Mie scattering
- Multiple scattering with application to aerosols and clouds
- Absorption

.

Trace Gas Levels, Sources, and Sinks
- Anthropogenic, biogenic, soil, and ocean emissions
- Wet and dry deposition

Atmospheric Chemical Transport Models
- Higher level of understanding than required for all students
- Level of understanding as covered in Chapter 25 of Seinfeld and Pandis

Experimental methods in laboratory studies of atmospheric processes

Experimental methods in field observations of atmospheric trace gases

Experimental methods in field observations of aerosol size and composition

Essential Knowledge List for Radiative Transfer and Remote Sensing Students

This document serves as a summary of the background knowledge that is expected of PhD level students specializing in radiative transfer processes and/or remote sensing at Georgia Tech.

- The role of atmospheric radiation in the Earth's system (energy budget, atmospheric dynamics and thermodynamics, and photochemistry).
- The nature of solar and thermal IR atmospheric radiation. Concepts of scattering, absorption, and emission. Main radiation laws. Blackbody radiation.
- Sun as an energy source. Solar spectrum and solar constant.
- Basics of gaseous absorption and emission. Concepts of a spectral line and a band. Absorption by atmospheric gases in IR, visible, and UV regions.
- Basics of interaction of electromagnetic radiation with aerosol and cloud particles. Single-scattering by spherical and non-spherical particles. The nature of light absorption by particulate matter. Lorenz-Mie theory.
- Fundamentals of the thermal IR radiative transfer. Principles of a line-by-line approach. Correlated K-distribution approximation.
- Principles of multiple scattering. Methods for solving the radiative transfer equation with multiple scattering and absorption (Two-stream and Eddington's approximations, Discrete-ordinates method, Adding method, Monte Carlo). Radiative transfer with polarization.
- Earth's energy balance. Direct and indirect radiative forcings. Radiation budget at the surface. Radiative feedbacks.
- Radiative heating and cooling rates.
- Actinic fluxes. Basics of photochemistry.
- PAR. Basics of photosynthetically active radiation and plant functioning.
- Radiation codes in regional and global atmospheric dynamical models.

Basic principles of remote sensing of atmosphere, and land and ocean surfaces.

- Principles of passive remote sensing using extinction and scattering. Scattering as a source of radiation. Multiple scattering. Applications: Sensing of ozone in the UV region. Ocean color. Sensing of clouds and aerosols (retrieval of optical depth and particle sizes)

- Principles of passive remote sensing using emission. Applications of passive remote sensing using emission: Sensing of sea surface temperature (SST). Sensing of clouds and precipitation.
- Principles of sounding by emission. Sounding of the temperature profile. Sounding of trace gases and air pollution
- Remote sensing of radiative energy balance components (SW and LW).
- Principles of active remote sensing: Radars and lidars. Applications of radars: Sensing of clouds, precipitation, and winds. Applications of lidars: Sensing of water vapor and trace gases. Sensing of aerosols and clouds.
- Remote sensing of land surfaces. Basics of retrievals of NDVI, fPAR, surface temperature, and soil moisture.
- Applications of satellite remote sensing in weather predictions.

Recommended Textbooks:

An Introduction to Atmospheric Radiation, K.N. Liou, 2002.

A First Course in Atmospheric Radiation. G.W. Petty, 2006

Radiative Transfer in the Atmosphere and Ocean. G. E. Thomas and K. Stamnes, 1999.

Absorption and Scattering of Light by Small Particles. C. Bohren and D. Huffman, 1983.

Information on Georgia Tech Remote Sensing Certificate

http://www.catalog.gatech.edu/colleges/cos/eas/grad/certificates.php

Basic Computing Skills

- Needs will vary: some combination of Matlab, IDL, and Fortran.
- Working with large datasets (e.g., HDF, netCDF)

Essential Knowledge List for Oceanography Students

This document serves as a summary of the background knowledge that is expected of PhD level students specializing in Oceanography at Georgia Tech. The information listed here as essential knowledge for all students is covered in five graduate courses: Oceanography, Ocean Dynamics, Environmental Data Analysis, Introductory Fluid Dynamics and Synoptic Meteorology and Ocean Biogeochemical Cycles. Other courses that may be useful for some students depending on their background and research focus include Thermodynamics of Atmospheres and Oceans, Ocean Modeling, Introduction to Climate Change, Turbulence in Geophysical Flows, Paleoceanography and Paleoclimate, Large Scale Atmospheric Circulation, Remote Sensing and data analysis, Climate Dynamics. Undergraduate technical training in calculus-based physics, and mathematics (up to vector calculus and ordinary differential equations) is assumed and is not explicitly covered in graduate coursework. Students with no undergraduate training in Earth System Science would benefit from a TA assignment in one of the EAS freshman-level courses.

Descriptive Knowledge of the Atmosphere and Climate

- The origin of the ocean basins, marine sediments, properties and chemistry of seawater.
- Mean and seasonal ocean circulation, waves, tides, currents, shallow water processes.
- Ocean biogeochemical cycles (e.g. carbon, nitrogen, phosphorous, oxygen cycles)
- Fundamental aspects of ocean circulation and biological productivity (coastal and open ocean).
- Physical oceanography of major current systems (e.g. gyre-scale circulations, boundary current systems and tropics).

Fundamentals of Ocean Dynamics

- Eulerian and Lagrangian kinematics.
- Equations of mass, momentum, and energy in a rotating frame of reference.
- Vorticity and divergence.
- Scaling and geostrophic approximation.
- Potential vorticity.
- Ekman layers.
- Primitive equations, equation of state for sea water.
- Barotropic and baroclinic instability.

Theory of ocean circulation

- Steady circulation in the oceans: quasi-geostrophy on the beta plane and planetary geostrophy on the sphere, Ekman pumping, wind- and thermally driven ocean circulation models, western-boundary current dynamics, and abyssal circulation.
- Wave motion in the ocean: Basic ideas of geophysical wave motion in rotating, stratified, and rotating-stratified fluids (e.g. Rossby, Kelvin, internal, gravity waves.).

Oceanography and Climate

- Global energy balance, surface energy balance, radiative transfer and climate.
- Hydrological Cycle
- Atmospheric circulation, ENSO, monsoon circulations, and fundamentals of air-sea coupling and interactions.
- Climate variability (e.g. interannual, decadal, centennial time scales), forced and intrinsic.
- The role of the ocean in climate change.

Turbulence in geophysical systems

- 3-dimensional, 2-dimensional, and quasi-geostrophic turbulence.
- Influence of stratification and rotation.
- Parameterization of turbulent processes in ocean models.

Modeling the ocean

- Numerical modeling of the ocean circulation
- Strengths and weaknesses of ocean models and different approximations
- Parameterizations

Recommended reading

Textbooks for learning or reviewing essential knowledge topics are
(1) *Open University Press: Ocean Circulation*
(2) *Atmospheric and Oceanic Fluid Dynamics* by G. Vallis, Princeton University Press, 2006,
(3) *Discrete Inverse and State Estimation Problems*, by Carl Wunsch, Cambridge Press, 2006,
(4) *Ocean Biogeochemical Dynamics*, by Jorge Sarmiento and Nicolas Gruber, Princeton University Press, 2006.

Basic Computer Skills

- Basic Unix/Linux, cluster and networked computer theory/tools
- Matlab
- Fortran (ability to function with any code)

Essential Knowledge List for Geophysics Students

This document serves as a summary of the background knowledge and skills that are expected of PhD level students in Geophysics at Georgia Tech. Outside of the additional knowledge identified for specific subdisciplines (denoted by bold acronyms), the information listed here will mostly be covered in one of a few “core geophysics courses”, short courses, individual research, or can be gained through participation in the geophysical seminar series. Much of the basic knowledge and math skills should have been covered in undergraduate courses (e.g., *Physics (I,II), Calculus series, Intro. Geophysics*), and hence may not be explicitly covered in these courses. The graduate-level “core courses” are *Geodynamics*, *Seismology*, and *GeoFluids*. Note that these courses are not meant to be requirements for all students, but are the first-level graduate courses that most students will take.

Basic Knowledge:

*((**S**) Seismology, (**Gd**) Geodesy, (**V**) Volcanology/Multiphase Flow, (**Sp**) Space Physics, (**Gm**) Geomorphology)*

- Plate tectonics theory: kinematic and dynamic processes, major current plate organization
- Planetary atmospheric structure (P,T,ρ)
- Fundamentals of heat transfer (conductive, radiative and convective)
- Major earth materials, elemental composition, density and location
- The 1D mechanical, compositional, density, and seismic velocity Earth model
  - 1st order deviations as associated with continental and ocean lithosphere and plate tectonics
  - Similar information for relevant planetary bodies (**Sp**)
- Fluid and solid mechanics: real-earth elastic and viscous moduli, stresses, flow and strain values
- Gravity: Universal law of gravity, the geoid, and structural anomalies
- Scaling, self-similarity and power-laws in nature
- Simplified phase diagrams
- Tsunami: Gravity wave propagation, causal factors, run-up height factors
- Fluid through porous media: Darcy’s law
- Basic understanding of radioactive nuclide decay
- Electromagnetism: Basic (E/M relationship, potentials, etc.)
- Statistics and error analysis: T-,F-tests, χ^2 , random vs. systematic error
- Hazard analysis of earthquakes, volcanism, tsunami, and space weather
- Basic scientific paper writing and presentation skills
- Basic knowledge of geophysics tools: reflection/refraction seismology, airborne/satellite remote-sensing (gravity, magnetism, InSAR, Lidar), GPS
- Time series analysis: digital signal processing, FFT, f-domain, filtering, convolution, correlation (**Gd, S**)

Math Skills

- Taylor, Fourier series
- Mathematical background: Scalars, vectors, and tensor, Matrix algebra, Vector Calculus
- Analytical diffusion/conduction calculations (computation of 1-D diffusion eqn,)
- Non-dimensionalize equations

Basic Computer Skills

- Matlab
- Computational algorithms (basic familiarity with compiled languages;, e.g. Fortran)
- ArcGIS (**Gm**)
- Basic Unix/Linux, cluster and networked computer theory/tools, Unix shell scripting, GMT (**Gd, S, V**)
- SAC (**S, Gd**)

Seismology

- Elastic wave propagation
- Snell’s Law (including Fermat’s and Huygen’s principles)
- Types of seismic waves, controls on velocity, important seismic phases within the Earth
- Geometric spreading, anelastic and scattering attenuation (**S)**
- Seismic anisotropy (**S, Gd**)

Geodesy
- Okada models of slip induced deformation (**S**, **Gd**)
- Mogi model of spherical source deformation (**Gd**, **V**)
- Limitations of analytic vs. numerical models of deformation (**Gd**)
- Basic theory of InSAR and GPS data reduction (**Gd, Gm**)

Earthquakes and Faults
- Elastic rebound theory
- Fault characterization using geologic, geophysical, and lab studies
- Controlling factors for earthquake occurrence: geographic location, strength and stressing requirements
- Basic earthquake source parameters:
    - Earthquake rupture properties: directivity, length, width, slip and strength
    - Magnitude-types and calculations, seismic moment, stress drop (**S, Gd, Gm**)
    - Corner frequency, and radiated energy (**S**)
- Focal mechanisms, moment tensors, Anderson's Theory of Faulting, deviations (**S, Gd, Gm**)
- Mohr-Coulomb failure, slip-weakening, Coulomb/Amonton friction, rate- and state friction, (**S, Gd, Gm**)
- Omori's law of aftershock occurrence (**S, Gm, Gd**)
- Modified Mercalli Intensity scale, contributing factors in ground shaking intensity (**S, Gd, Gm**)

Fluid Dynamics
- Conservation relationships for thermal energy, mass and momentum
- Boundary layer analysis (**V, Sp**)
- Reynolds number, Stokes number, Froude number, particle flow and forces (**Gm, V**)
- Plumes, jets and gravity currents (analytic models and scaling) **(V)**
- Turbulent flows and Kolmogorov theories (and transition from laminar to turbulent flow) (**Gm, V**)
- Familiarity with compressible fluid dynamics (shock relations and choked flow) (**V**)
- Kinetic theory of gases (**V**)
- Basic understanding of algorithms for convection/melting including source terms (radioactive nuclides, linear melting models) (**V**)

Volcanology and Magma Dynamics
- Mantle melting relations (wet and dry)
- Basic understanding of compositional variation in magmas (basalt – rhyolite) and their physical properties
- Volcanic system types, eruption styles and mechanisms
- Fragmentation criteria for magma in volcanic conduits, and its relation to eruptive style (**V**)
- Convection scaling and relate this to cooling magma chambers (and describe the Biot effect) (**V**)

Planetary and Rock Magnetism
- Magnetic dipole field, basic dynamo theory, magnetic reversals (field evidence)
- Curie point and magnetic susceptibility
- Space weather (sun-earth connection)
- General understanding of magnetic reconnection (**Sp**)
- Magnetospheric/Auroral generation and dynamics (**Sp**)
- Electromagnetism: Plasma, and wave dynamics (**Sp**)

Geomorphology and Geology
- Basic understanding of geochronologic/thermochronologic techniques
- Feedbacks between mountain building, erosion, and climate
- Fundamentals of geologic mapping
- Field methods (geomorphic mapping, landform surveying, geochronology sample collection) (**Gm**)
- Paleoseismology and observations of faulting (**S, Gd, Gm, V**)
- Threshold of critical power in streams (**Gm**)

Essential Knowledge List for Geochemistry Students

This document identifies the basic, or core, knowledge and skills expected from PhD candidates in geochemistry at Georgia Tech. The concepts and tools listed below represent the essential background needed to prepare for the doctoral comprehensive examinations in the field of geochemistry. The core knowledge also prepares PhD students for successful professional careers upon graduating.

Graduate students acquire the required basic knowledge and skills through course work, self-study, individual research, short courses and participation in the geochemistry seminar series. Usually, this is done during the first two years of enrollment in graduate school. Students with prior academic training at the graduate level may already have met all or part of the requirements.

The list below is divided in two parts. Part I covers the basic knowledge expected from all geochemistry students, irrespective of their specialization. Part II covers the basic knowledge for the geochemical subdisciplines represented at Georgia Tech.

Part I: General

- Basic principles and concepts of general, inorganic and organic chemistry
- Laws of thermodynamics, entropy, free energy, chemical potential, standard states, Phase Rule, Gibbs-Duhem relation, phase diagrams
- Application of equilibrium thermodynamics to geochemical systems: gases, mixtures, mineral equilibria, solid solutions, aqueous solutions
- Activity-concentration relations, Debye-Hückel equation, ion pairs, complexes
- Redox equilibria, redox potential, pe, pe-pH diagrams
- Computer-assisted thermodynamic calculations (MINTEQ, MINEQL, PHREEQ, etc.)
- Empirical rate equations, reaction mechanisms, Arrhenius equation, collision theory, transition state formulation of rate constant
- Structure of mineral-water interface, adsorption isotherms, controls on weathering and mineral formation
- Diffusion, advection, dispersion and their mathematical representations
- Conservation equations, boundary and initial conditions, analytical solutions (simple cases)
- Basic knowledge of the chemistry of natural waters, earth surface minerals and natural organic matter
- General characteristics of oceanic and atmospheric circulation
- Stable isotopes: fractionation, delta notation, Rayleigh model

Part II: Subdisciplines

1. Biogeochemistry

- General overview of the water, carbon, nitrogen, sulfur, phosphorus, silicon and iron cycles, sources and sinks of greenhouse gases
- Detailed understanding of carbonate chemistry and its role in carbon cycling

- Dynamic modeling: mass balance equations (ODEs), initial conditions, scenarios, numerical solutions, residence times, response times

2. Chemical oceanography

- General knowledge of geochemical analysis and sampling of ocean water, particulate matter and seafloor sediments
- Basic understanding of
  - physical oceanography (surface, deep and boundary circulation),
  - biological oceanography (productivity, nutrients, trophic interactions),
  - marine geology (plate tectonics, ocean basin morphology, proxies), and
  - early diagenesis (organic matter degradation, redox zonation, bioturbation, preservation)

3. Geomicrobiology

- Theoretical basis of microbial kinetics and bioenergetics
- Detailed knowledge of carbon, nitrogen, sulfur, and selected metal (Fe, Mn, Cr, U, As, …) geochemistry and geomicrobiology
- Basic knowledge of contaminant hydrology and bioremediation

4. Mineral surface geochemistry

- Mineral structure and crystal chemistry of common oxides, silicates and carbonates
- Structure of mineral surfaces, surface complexation theory
- Theories of mineral nucleation, growth and dissolution

5. Organic geochemistry

- Methods of isolation of dissolved organic matter (DOM) from natural waters
- Structure, composition and properties of natural (DOM) in freshwater and marine environments
  - Elemental composition of DOM
  - ^{1}H and ^{13}C NMR spectroscopy of DOM
  - FTICR mass spectra of DOM
  - Analyses of biomolecules in DOM (amino acids, sugars, fatty acids, etc.)
- Detailed understanding of the role of DOM in metal complexation and acid-base chemistry of natural waters

6. Geochemical modeling

- Working knowledge of at least one programming language (Fortran, C++, …) or one mathematical software environment (e.g., MATLAB)
- Derivation and implementation of mass conservation equations for multi-component reaction-transport systems (PDEs)
- Finite difference, finite element numerical calculations

Essential Knowledge List for Paleoceanography/Paleoclimatology Students

Minimum Recommended Coursework (all students responsible for the material covered in these courses)

Paleoceanography/Paleoclimatology
Oceanography
Introduction to Climate Change
Isotope Geochemistry
Ocean Biogeochemical Cycles

Extended Coursework (students are also responsible for the material in the courses they selected to best complement their research area). This might include more advanced coursework in ocean/atmosphere dynamics, geochemistry, numerical methods, etc.

If you know the material presented in these courses well, and done some extra reading in areas close to your research project, you will do well on your comprehensive exam.

A. General Earth Science Knowledge (know to the level presented in a class for undergraduate non-majors)

How and when did the earth form, basic earth structure
Basics of Plate Tectonics, Earthquakes
Rock cycle and chemical composition of earths
Basic Earth History
Atmospheric and Ocean composition
Greenhouse effect and global warming
Recent exciting developments

B. General Climate Knowledge

Global energy balance (including albedo, greenhouse gasses)
Global scale atmospheric circulation patterns
Seasonality and monsoons
Atmospheric composition, clouds, aerosols
Role of ocean in climate
ENSO & coupled ocean-atmosphere phenomenon

C. General Oceanographic Knowledge

Wind driven circulation (Ekman transport/upelling/convergence, Gyre circulations)
Major ocean currents (where and why)
Deepwater formation (where and why)
Deepwater circulation patterns

D. Ocean Biogeochemistry

Primary production (where, why, what organisms)
Distribution of major nutrients
Role of trace elements
Gas solubility and air-sea exchange
Distribution of oxygen
Carbon cycle
- Speciation
- Air-sea exchange
- Carbonate solubility

Ocean sediments (major components and controls on composition)

E. Isotope Geochemistry

Oxygen isotopes in water (atmosphere, freshwater, ocean) and carbonates
Carbon isotopes in the environment (DIC, organic matter, carbonates)
Basics of mass spectrometry including calibration
Carbon-14 and U-series dating

F. Paleoclimate Methods

Familiarity with proxies (how they work, strengths and weaknesses, geographic and temporal limitations) for:
- Marine records (sediment cores, corals), Terrestrial records (ice cores, stalagmites, groundwater, etc.)
- Proxies include, isotopic, sedimentological, ecological, biochemical, trace elements, noble gases, etc.

Paleoclimate modeling – boundary conditions, forcing, coupling, hierarchy of models
Timescales/chronologies -- methods, limitations, controversies

G. Climate History

Knowledge of basic state of ocean/atmosphere system, how we know what we know, ideas about reasons for changes

Holocene climate variability
The last deglaciation and abrupt climate change during MIS Stage 3
LGM
Pleistocene glacial cycles
Cenozoic "deterioration"
Cretaceous climate
Early evolution of ocean/atmosphere/climate

H. Controls on Past Climate

What processes drive climate change? What are feedbacks that are active on various timescales?

Milankovitch timescales
Longer Term changes (Timescales from billions to millions of years)
Shorter term changes (Millennial, century, decadal)

I. Links to Anthropogenic Climate Change

How does your work relate to anthropogenic global warming? How could your results be used to reduce the uncertainties of future climate projections?

J. Paleoclimate Perspective

Where has the field been? Where is it going? Where does your work fit into the broader picture? What problems are the most pressing? Why?

K. Other Specific Issues Relevant to your Thesis Project

If your research involves corals, know something about coral biology and chemistry. If your research involves planktonic foraminifera, read up on planktonic foraminifera ecology. If your research involves lead isotopes, know in detail about the cycling of lead in the earth system. If your research involves the Atlantic overturning circulation, know the details about what controls this. Etc.

Recommended readings:

Basic Geology text for undergraduate non-majors, Read news sections in *Science* and *Nature* every week.

Dennis Hartmann: Global Physical Climatology

Open University Press: Ocean Circulation

Sarmiento and Gruber: Ocean Biogeochemical Cycles

Gunther Faure: Isotope Geology

Paleoclimate topics: See class assignments for Paleoclimate, read paleoclimate articles in *Science* and *Nature* as they come out. Read relevant reviews published over the past several years.

Paleoceanography, GRL, EPSL, GCA, Journal of Climate: Read articles relevant to your research

Essential Knowledge List for Land Surface Processes and Hydrology Students

Basic Hydrologic Concepts

- Conservation Equations
- The Watershed – From small to Large Scales
- Regional Water Balance Regional Evapotranspiration
- Storage, Storage Effects, and Residence Time
- Hydrologic Modeling

Climate, the Hydrologic Cycle, Soils, and Vegetation: A Global View

- Energy Budget of the Earth
  - Latitudinal Energy Transfer
  - The General Circulation and the Distribution of Pressure and Temperature
- The Global Hydrologic Cycle
  - Distribution of Precipitation
  - Distribution of ET
  - Distribution of Runoff
- Land-Atmosphere Fluxes of Water and Energy - What Balances the Incident Solar Radiation
  - Longwave radiation – surface emissivity
  - Surface reflectance of solar radiation
  - Sensible heat fluxes
  - Evapotranspiration
- Climate, Soils, and vegetation

Basic Issues in Regional Scale Hydrological Modeling

- Hydrological time scales of a basin
- Physical components of a hydrological model
- Statistical Models
- Bulk models verses routing models
- Surface flow versus subsurface flow

Land-Atmosphere Interactions

- Micrometeorological Methods for Measuring Mass and Energy Flux Densities
- Biosphere/Atmosphere Interactions: Models for Integrating Leaf Scale Fluxes to the Canopy Scale
- Biosphere/Atmosphere Interactions: Integrating and Scaling from Canopy to Landscape Scales
- Plant-Canopy Micrometeorology
- Planetary Boundary Layer Turbulence and Characteristics

Treatments of land-atmosphere processes in the regional and global climate models