Earth System Modeling - EAS-4610-A

Class: M/W 11:00-12:15 in Ford ES&T L1118

Office Hours: Friday 11:00-12:15 (or by appointment) at my office (ES&T 3232) or BlueJeans if preferred.

Course description: This course covers the fundamentals of numerical methods and their application to problems in Earth sciences. Course content includes differential equations (ordinary and partial), integrals, root-finding and linear algebra. This course is targeted at undergraduate students in Earth & Atmospheric Sciences, and is the undergraduate equivalent of EAS 6130, thought is covers somewhat less material at a more deliberate pace.

Prerequisites: An undergraduate-level understanding of calculus and differential equations (i.e. MATH 1552, 1553, 2551, 2552). Some introductory ability with MATLAB or Python (i.e. CS 1370/1371): defining variables, performing matrix operations, making plots, using loops and logical operators. Please talk to Prof. Robel if you are concerned about coding.

Course Goals and Learning Outcomes: At the end of this course, students should be able to use basic numerical methods to solve simple equations or model systems of equations. Students should also have more confidence with using MATLAB or Python to program simple numerical methods for solving fairly well-behaved problems in integration, differential equations, root-finding, and linear algebra.

Course References:

There is no required textbook, as course notes will cover all material required to complete assignments and assessments. Here are other useful textbooks to supplement lectures

1. G. Lindfield and J. Penny, Numerical Methods: Using MATLAB, Academic Press, 4th ed., 2018 (**E-book available through GT library (https://ebookcentral.proquest.com/lib/gatech/detail.action?docID=953183)**).

2. R. Slingerland and L. Kump, Mathematical Modeling of Earth's Dynamical Systems, Princeton U Press, Pbk edition, 2011 (**E-book available through GT library (https://ebookcentral.proquest.com/lib/gatech/detail.action?docID=664639)**).

Course Requirements and Grading: Problem sets every 2 weeks (50%), midterm individual project (25%), final group project (25%).

Problem sets are meant to challenge you with a problem that you have never seen before. Though figuring out an approach and solution to these problems may take some time, if you feel stuck or think the problem is incorrectly posed, please send me an e-mail or see me in office hours. **See "assignments" on the left Canvas menu for a list of assignments with problem sheets and**

submission site. Solution sheets will not be provided after grades are returned, but Prof. Robel can work through a problem in class or in office hours if students have questions.

Midterm projects will be completed on an individual basis. These projects should use ordinary differential equations to model an Earth system process. The topic may involve reproducing or modifying simple models from published papers. Two class sessions will be devoted to short (7 minute) lightning talks on the project, with 3 minutes of discussion afterward. To encourage participation and discussion of the lightning talks, student will be assigned to prepare questions during certain talks. A short (4-6 pages not including references) report will include details of the model equations, numerical methods used, and select results.

Final projects will be completed in groups of 2-3. These projects should use partial differential equations to model an Earth system process. The topic may involve reproducing or modifying models from published papers. The final project deliverable will be an interactive notebook (either MATLAB or Python-based) with step-by-step description of model equations, numerical methods used to solve the equations, and dynamically-generated plots. Project notebooks will be stored as repositories on Github (with a mid-semester tutorial showing students how to use Github).

Grading Scale: A: 90-100%, B: 80-90%, C: 70-80%, D: 60-70%, F: 50-60%

Collaboration & Group Work: You may find it useful to discuss assignments with your fellow students. The course policy is that discussion is acceptable if the goal is to determine an approach to a possible solution. However, sharing/comparing complete solutions is not allowed, including code, derivations or plots from your final write-up. If you discuss an assignment with someone else, please put their name on the first page of your submitted solutions.

Attendance and Participation: Attendance is not required. All classes will be recorded and posted to canvas. However, a considerable portion of the course material will be covered in the class session. Though textbooks support these lectures, they cannot exactly replace the material covered in lecture. If you plan on missing multiple class session in a row, please e-mail me ahead of time. Lecture notes and code from class will be posted on Canvas.

Extensions, Late Assignments, & Re-Scheduled/Missed Exams: Late assignments will only be accepted without penalty if you have asked for permission (with GT-approved excused or for other extenuating circumstances) at least 24 hours before the assignment is due with a proposed date of submission. Otherwise, assignments submitted later than the end of class time on the day that they are due will automatically be deducted 20% credit. Assignments will not be accepted more than 24 hours late (i.e. you will receive no credit for the assignment) unless you have received prior permission.

Student Use of Mobile Devices in the Classroom: You are allowed to use whatever tool (laptop, tablet, etc.) you need in class to take notes and generally be successful. However, unless you have asked me ahead of time to be able to use your phone during class (to take notes or for emergency purposes), using your phone in class is not permitted. If any emergency comes up unexpectedly in class that requires you to use your phone, please let me know.

Academic Integrity: Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. For information on Georgia Tech's Academic Honor Code, please visit **this link (http://www.catalog.gatech.edu/policies/honor-code/)**. Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.

Course Schedule:

Assignments in red. Notes in blue. Code in purple.

Week 01: Preliminaries: course logistics, why we need numerical methods, MATLAB/Python refresher

Week 02: ODE review and Box models. Examples: climate energy balance model, ocean carbon, ocean overturning (PS0 due Wednesday)

Week 03: Solving ODEs: forward Euler method, backward Euler method. Examples: nuclear decay

Week 04: Higher-order ODE methods: Runge-Kutta, predictor-corrector, Euler-Richardson. Examples: Newton's equations of motion, Kepler Orbits (PS1 including midterm project abstract due Friday)

Week 05: ODEs continued + stability and convergence of numerical methods

Week 06: Numerical integration: midpoint rule, trapezoid rule, Simpson's rule. Examples: Sea Level Equation (PS2 due Monday)

Week 07: Midterm project talks. Midterm reports due Friday

Week 08: (No class Monday - Fall recess) How to use Github

Week 09: Review of partial differential equations. Advection equation. Finite difference, upwind scheme. Example: Ocean pollution (PS3 due Monday)

Week 10: Diffusion equation. Crank-Nicolson scheme. Advection-diffusion. Examples: Heat diffusion, Hillslope erosion

Week 11: Wave equation. Example: seismic waves (PS4 due Wednesday)

Week 12: Review of root-finding problems, root-finding methods: bisection, Newton-Raphson. Examples: Halley's Comet, finding steady-states (PS4.5 - Final project abstract/group due Wednesday)

Week 13: Review of linear algebra. Inverse problems, matrix inversion, matrix decomposition, eigenvalue problems.

Week 14: (No Class Wednesday for Thanksgiving) Linear algebra continued. Examples: nuclear decay chain, gravity inversion (virtual). (PS5 due Tuesday)

Week 15: Fun stuff: cellular automata - example: forest fire model (virtual). (Working/rough notebook of final project model due on GitHub Tuesday) - Wednesday virtual project office hours based on rough notebook

Week 16: Fun stuff: big computers (virtual). (Final project notebook due Tuesday)

Course Summary:

Date	Details	Due