Earth System Modeling (graduate section)
EAS 6130
Fall Semester 2021

Scheduling: Tuesday and Thursday, 09:30-10:45 am, room Howey S104

Lectures: Tuesday and the first half of the Thursday session are reserved for lectures and introduction to new fundamental concepts.

Programming sessions: Students are required to bring their laptops on Thursday, where we will revisit the fundamental notions introduced in class and apply them during practical sessions.

Instructor
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Teaching Assistant
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Office Hours

Tyler Vollmer:	Monday and Wednesday, 01:30 - 03:00
Sven Simon:	Friday, 11:00 – 12:30

Grading

Homework	30%
Exams (two, equally weighted)	40%
Term project (written report)	30%

Grading scheme: 100-85%: A, 85-70%: B, 70-60%: C, 60-50%: D

Suggested Literature
Though *not* required, I recommend "Computational Physics" by Mark Newman as a reference book.
https://www.amazon.com/Computational-Physics-Mark-Newman/dp/1480145513

Important Dates:

01 October 2021:	abstract for final project due
21 October 2021:	first exam (80 minutes)
23 November 2021:	final project report due
02 December 2021:	second exam (80 minutes)

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TENTATIVE LECTURE TOPICS

- **Root-finding methods** (bisection, Newton-Raphson)

- **Numerical Integration** (midpoint rule, trapezoid rule, Simpson's rule)

- **Ordinary differential equations (ODE) of first order** (Euler-Forward, Euler-Backward, centered Euler scheme, stability, consistency, convergence, Lax-Richtmeyer-Theorem)

- **Box models** (coupled systems of ODEs, tridiagonal matrix inversion, Thomas algorithm, *examples:* nuclear decay chains, daisy world, predator-prey problem)

- **Higher-order ODEs** (Runge-Kutta methods, Predictor-Corrector and Euler-Richardson, *examples:* Newton's equation of motion, Kepler's orbits, particle motion in Earth's ionosphere)

- **Partial differential equations** (advection equation, diffusion equation, Laplace equation)

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GEORGIA TECH HONOR CODE

Students in this class are expected to abide by the Georgia Tech Honor Code and avoid any instances of academic misconduct, including but not limited to:

- Possessing, using, or exchanging improperly acquired written or oral information in the preparation of a paper, a homework assignment or for an exam.

- Substitution of material that is wholly or substantially identical to that created or published by another individual or individuals.

- False claims of performance or work that has been submitted by the student.

See the published Academic Honor Code for further information. The complete text of the Academic Honor Code may be found at

http://www.deanofstudents.gatech.edu/integrity/policies/honor_code.html

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TERM PROJECT INFORMATION

Project Guidelines

An important part of this course is the numerical model that you will develop for an atmospheric, geochemical, geophysical, planetary/ space physics, geotechnical, environmental, hydrologic, or biogeochemical process or system. As a general guideline for the choice of a project, consider some of the physical or chemical systems or processes that you have studied within EAS.

Non-EAS students should use examples from their own fields of study. Graduate student projects should be related to the student's research.

The term project is a group project, with each group having two members. The two members are expected to share work equally within the group (although you can of course divide up the tasks).

As a general rule, you should choose a modeling project that relied on solving fundamental equations of mathematical physics numerically in space and/or time. Ideally, your project should be based on relatively simple equations that can first be solved analytically for some easy case (e.g., a steady-state solution or a solution that reduces the spatial dimensions of the problem). Then you want to discretize your equations (we will study this in the first half of the course) and develop a computer program that solves the equations numerically. This computer program will allow you to test your numerical approximations against the analytical solution, to test the sensitivity of the process/system to variations in important parameters in the problem, to calibrate the model using a data set, and (possibly) to verify the model using multiple data sets. We strongly encourage the use of the scientific computing language Matlab, although we will consider requests to use compiled languages such as Fortran, C, or Pascal.

It is desirable that the modeling be motivated by the need to understand a process or system. Thus, it is helpful to develop a model for a system for which you have existing real data. These data can be taken from any literature source, from something you have done in another EAS course, or from a Web site that provides real data. The data do not have to pertain directly to the final model, but may instead be relevant to some intermediate step in your model (e.g., a steady-state solution).

Project Report Outline

1. Introduction
   What is the main theme?
   Why is it important?
   What are the motivations for the study?
   How is it currently being studied?
2. Modeling approach
   What are the fundamental physical/chemical/etc. processes?
   Include all relevant equations.
   Describe all terms and parameters.
   Describe all assumptions being made.
   Describe the numerical methods used.
3. Results
   What tests did you run with the model?
   Describe the results.
   How do the results compare with any analytical solution you developed?
   How do the results compare with those in the literature?
   How do the results compare to data that pertain to this process?
   How can you explain any differences?
4. Conclusions
   What did the model tell you about the process you were studying?
   How could the model be improved?
5. References
   Follow the format described in the next section
6. Appendix
   Printout of model code with commentaries

Some Specific Guidelines

- **<u>The project report may be a maximum of 12 double-spaced (12-point font, with 1 inch margins) pages. Each team (two members) needs to submit one report.</u>** Figures, references, tables, appendices, and program listings are NOT included within the 12-page count. Please use an appropriate equation editor for all equations and spell-check before handing in the documents.
- Figures must be sequentially numbered and clearly labeled. Every figure requires an explanatory caption. Any figure taken from other scientists' work should be clearly labeled as, for example, "After [Jones et al., 1996]". You may not use the original author's figure caption.
- Any values you use in your model should be attributed to a reference. You must also provide an explanation for why this value was chosen in the first place.
- You must detail your assumptions.
- You should compare your model results to at least one set of real data and statistically quantify the agreement. You must also explain why your model

results may not provide a good agreement to the data and give suggestions for ways in which the model might be improved.

- You must include a listing of your code as an appendix to your paper.
- References should be clearly made using the standard mode of reference for the Earth Sciences. Within the text, a reference is made as: [Jones et al., 1996]
- Journal reference: Jones, R. L., S. Davis, and R. Smith, Article's title in small letters (except for proper names like Kansas), *Jour. Hot Air*, 67, p.33-87, 1999.
- Book article: Jones, R. L., Chapter's title, in: eds. S. Chimera and D. Boondoggle, Book's name, New York, McDuffy-Holt and Col, p.110-128, 1996.

Examples of Project Topics

Diffusion-limited aggregation (DLA) models
Stochastic model of porous media generation (metropolis algorithm)
Advection-diffusion reaction equations
3-body gravitation and orbits
Chemistry of the ozone layer
Urban pollution chemistry
Dispersion of pollution plumes
Carbon or nitrogen cycling
Oceanic nutrient cycling
Evolution of spreading ridges and initiation of magmatism
Ocean circulation
Biogeochemical reactions in soils
Hydrothermal processes
Atmospheric radiative balance
Chaos in some natural system
Temperature structure and heat transfer of solid Earth
Growth of volcanoes
Geyser eruptions
Magma differentiation from mantle partial melting
Plant uptake of groundwater
Melting of an iceberg
Erosion, sediment transport, and deposition
River meandering
Seismic wave travel time through multi-layered Earth
Contaminant transport through soils or water
Eutrophication of lakes
Evolution of propagating rifts
Slope failure
Brittle faulting in the crust
Heat, chemical and/or fluid flow in porous or fractured rocks
Shallow water waves

Coupled flow and saline intrusion in a coastal aquifer
Tidal pumping of a phreatic aquifer
Stalagmite growth
Climate change due to solar variability
Vertical infiltration of heavy metals in soils
Seismic tomography