Earth System Modeling
Syllabus, Fall 2019

Instructors: Dr. Mac Cathles email: mcathles@umich.edu
Dr. Samuel Kachuck email: skachuck@umich.edu

Class Location: 2236 CSRB
Lab Location: 2230 CSRB (CAEN)
Office location: 1216 CSRB; 1541C CSRB,
Office hours: **Wednesdays and Thursdays, 2 – 4 pm**
Class Times: Tuesdays and Thursdays, 9:30-11:30AM

Textbooks (optional):
** Mathematical Modeling of Earth's Dynamical Systems (Slingerland and Kump, 2011)
An introduction to Computer Simulation Methods: Applications to Physical Systems (Gould and Christian, 2006)
Numerical Recipes: The Art of Scientific Computing
Mathematical Modeling Techniques (Rutherford Aris, 1994)

All textbooks are available from the library for checkout.
** electronic copies are available through library, access link on campus or using VPN

Course Overview: This course is an introduction to Earth System Modeling- the art and science of reducing complex natural interactions on Earth into quantitative rules that can be solved using computers.

Course Aim: We will learn numerical methods and programming, with a focus on those methods and practices that we have found useful over the years. The aim is to provide students with practical tools that can be used to formulate models and then solve the ordinary and/or partial differential equations that ensue.

Prerequisites: Students should have been exposed to ordinary and partial differential equations and (some) linear algebra. Homework assignments will involve programming in MATLAB (or an alternative language of the student's choice such as Python). No programming experience is required. However, some familiarity (or at least a keen willingness) to learn programming is a must.

Honor Code: You are free to collaborate with fellow class times on homework and labs, but the work you turn in must be your own, including code. When working collaboratively on code, you must credit classmates with section of code/algorithms obtained from others. Failure to do so will result in an honor code violation and will be forwarded to the honor council for investigation.

Grading:

Labs:	55%
Homework & Quizzes:	10%
Mid-term exam:	15%
Final project:	15%
Participation:	5%

Translation to Letter Grades:

Grade	Minimum %
A+	97.0
A	93.0
A-	90.0
B+	87.0
B	83.0
B-	80.0
C+	77.0
C	73.0
C-	70.0
D+	67.0
D	63.0
D-	60.0
E	50.0
F	40.0

Homework/labs:
We will have 6-8 labs throughout the semester. The labs will each involve developing a numerical model and performing experiments with the model. Some class time will be provided to work on the numerical model. Students are encouraged to work together and compare results, but each student must turn in their own work. Late assignments will be penalized 10% per day late. **If you need to turn an assignment in late contact us before the assignment is due.** Grading for each homework assignment is based on the following rubric:

Lab Grading Rubric for formal labs:
1. Introduction (10%): Should provide a concise summary of the problem, motivation and relevant scientific questions.

2. Method (15%): Should provide sufficient details for others to reproduce the results including relevant equations, numerical method, time step size , numerical value of all parameters used in the calculation, etc.

3. Results (25%): Summarize relevant results and address all questions posed in lab.

4. Figures (25%): All figures should have captions; axis, lines and markers should all be clearly labeled and all text must be legible (minimum font size 10).

5. Conclusions (25%): Summarize main results and answers to questions here

6. Significant digits (up to -10%): You will be penalized (up to 10%) for superfluous digits reported.

Final Project:
The final project will consist of developing a new lab for this course that illustrates concepts of numerical modeling. The project can illustrate ideas we covered in class or more advanced ideas. Deadlines for final project include:

1. You must provide me with a 1-2 paragraph summary of the topic of your project by October 18th; (worth 5% of final project grade)
2. A 1-2 page summary of the problem, including relevant equations and numerical method by November 22nd (you can use this as part of your final report); (15% of final project grade)
3. The final project description, with working code to solve the problem and solution is due on Dec 18th (85% of final project grade)

*Warning: We reserve the right to incorporate the best labs into future versions of this class.

Tentative Schedule

We can roughly divide the topics into (1) Ordinary differential equations and (2) Partial differential equations. Partial differential equations can be subdivide into Diffusive (parabolic), Advective (hyperbolic) and Steady-State (elliptic). Each of these different topics are interrelated, but each also has their own numerical methods and pitfalls.

Provided below is a very tentative outline. We reserve the right to rearrange, add or subtract topics depending on our progress and class interest.

Week	Tuesday	Thursday	Lab	Homework
Week 1, Sept 3, 5	Class preliminaries, What is a model and how do we make one?	MATLAB tutorial, Ex 1: Coffee cup cooling problem. Ex 2: forest fires	Lab 1: Forest fires and the spread of infectious disease	Homework 0: What is a model? Due on Sept5.
Week 2, Sept 10, 12	Simple models of forest fires and infectious diseases	Coffee cooling problem revisited: forward and backward Euler Formal error	Continue Lab 1	Homework 1 Plot and caption Lab 1 Due on Friday Sep 13
Week 3, Sept 17, 19	Limit cycles, predator-prey	Stability and stiffness Co-op: Euler Leapfrog	Lab 2: Predator-Prey, and chaos	Homework 2 due on Sept 19

Week 4, Sept 24, 26	Deterministic chaos, weather and climate	Continued	Lab 2 continued	Lab 2 Due on Friday September 28
Week 5, Oct1, 3	Introduction to climate and climate models: energy balance models	0-D energy balance modeling	Lab 3: Energy balance models	Homework 3 due on Oct 3
Week 6, Oct 8, 10	Linear algebra	1D Energy Balance Model	Lab 3 continued	
Week 7, Oct 15, 17	**Fall Break**	Coffee cooling problem revisited: Finite difference approximations	Lab 4: Snowball Earth Part 1	Lab 3 due on October 16
Week 8, Oct 22, 24	Finite difference approximations, error and stability	**Review for midterm exam**		Mid-term exam Tuesday, October 29
Week 9, Oct 29, 31	**Mid-term exam**	Snowball Earth and climate tipping points	Lab 5: Snowball Earth Part 2, continued	Lab 4 due on November 1
Week 10, Nov 5, 7	Work on lab 5	Vegetation and climate,	Lab 5: Snowball Earth Part 2, continued	Lab 5 due on November 8
Week 11, Nov 12, 14	How to order your variables in 2D	Matrix formulation of finite differences	Lab 6: Climate-vegetation interaction	
Week 12, Nov 19, 21	Diffusion and advection in 2D	**Thanksgiving**	Lab 6: Climate-vegetation interaction	Lab 6 due on November 26
Week 13, Nov 26, 28	Ground water flow, hydraulic head and all that	Interpolation and extrapolation of data	Lab 7: Ground water pollution	
Week 14, Dec 3, 5	Tracer advection, explicit versus implicit	Work on lab 7	Lab 7: Ground water pollution	Lab 7 Due on Dec 6
Week 15 Dec 10	Work on final project			Final project due Dec 18

Accommodation for disabilities:

The University of Michigan is committed to providing equal opportunity for participation in all programs, services and activities. If you think you need an accommodation for a disability, please let us know at your earliest convenience. Some aspects of this course, such as the assignments, in-class activities, or the way we teach may be modified to facilitate your participation and progress. Request for accommodations by persons with disabilities may be made by contacting the Services for Students with Disabilities (SSD) Office located at G664 Haven Hall. The SSD phone number is 734-763-3000. As soon as you make us aware of your needs, we can work with you, the Office of Services for Students with Disabilities, or the Adaptive Technologies Computing Site to help determine appropriate accommodations. We will treat any information about your disability with the utmost discretion.

Student Mental Health and Well-being:

University of Michigan is committed to advancing the mental health and wellbeing of its students. If you or someone you know is feeling overwhelmed, depressed, and/or in need of support, services are available. For help, contact **Counseling and Psychological Services (CAPS)** at (734) 764-8312 and https://caps.umich.edu/ during and after hours, on weekends and holidays, or through its counselors physically located in schools on both North and Central Campus. You may also consult **University Health Service (UHS)** at (734) 764-8320 and https://www.uhs.umich.edu/mentalhealthsvcs, or for alcohol or drug concerns, see www.uhs.umich.edu/aodresources. For a listing of other mental health resources available on and off campus, visit: http://umich.edu/~mhealth/.

Attendance, Participation, and Universal Learning:

Attendance and participation are highly important in this class. Please notify me of absences due to religious observance or University sporting events as soon as you can. I am committed to the principle of universal learning. This means that our classroom, our virtual spaces, our practices, and our interactions will be as inclusive as possible. Mutual respect, civility, and the ability to listen and observe others carefully are crucial to universal learning. Active, thoughtful, and respectful participation in all aspects of the course will make our time together as productive and engaging as possible.

Climate and Space Sciences and Engineering Diversity Statement:

The teaching and research mission of the Department of Climate and Space Sciences and Engineering is enhanced by learning from and working with a diverse intellectual community within an environment of full inclusion – a supportive and welcoming workplace that values all individuals and their perspectives, contributions and ideas. We welcome members with diverse global experiences across all forms of dimensions and intersections, including race, ethnicity and national origins, gender and gender identity, sexuality, class and religion. We are especially committed to increasing the representation of those populations that are underrepresented in the Earth and Space Sciences. We are committed to attracting, recruiting and retaining a diverse population of faculty, undergraduate and graduate students, and staff. We work to identify and promote practices and structures that support inclusion, safety and diversity's development in our department's work through programs supported by our Diversity Ally, mentoring activities and our student organizations.